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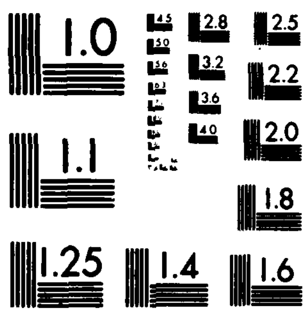

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AN ECONOMIC MODEL OF FUTURE COAL/
DENSIFIED REFUSE-DERIVED FUEL USE
AT WRIGHT-PATTERSON AFB OH

Richard G. Fedors, Captain, USAF

LSSR 97-81

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The use of alternate fuels in heating and power plants is one activity supporting Air Force long-range objectives to become more energy efficient and reduce dependency on petroleum products. Within the solid fuel conversion effort, goals have been set for increasing the percentage of total installation energy provided by coal and its products, refuse-derived fuels, biomass, and wood. To encourage development of alternate fuel use and gain operating experience, WPAFB undertook a thirty-month evaluation/demonstration of dRDF as a stoker boiler fuel in military heating plants (starting in May, 1979). This thesis examines the impact on plant operating expenses of burning coal:dRDF mixtures at that particular base. The figures for comparison were generated by a simulation model of the WPAFB heating system and environment. Projected yearly operating expenses were accumulated in the model and returned to present values for various fuel ratios, inflation rates, and discount factors. Under the assumptions made within the model, coal alone will remain less expensive to use than a mixture with dRDF until a local source of dRDF becomes available.

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AN ECONOMIC MODEL OF FUTURE COAL/ DENSIFIED REFUSE-DERIVED FUEL USE AT WRIGHT-PATTERSON AFB OH

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

By

Richard G. Fedors, BSEE
Captain, USAF

September 1981

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This thesis, written by

Captain Richard G. Fedors

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING MANAGEMENT

DATE: 30 September 1981

COMMITTEE CHAIRMAN

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CHAPTER I

INTRODUCTION

Background

The growing solid waste stream (45:49) from residential, industrial and agricultural sources in the United States has placed increasing pressure on our disposal methods. Almost 90 percent of the solid waste generated in this country is disposed of by landfilling (85:22; 59). As those sites inexorably fill up with garbage, municipalities seeking new landfills find themselves competing with other public and private interests for available land. Local opposition to the siting of new sanitary landfills, as well as state and federal Environmental Protection Agency regulations, can severely restrict the opening of replacement sites to handle the steady flow of municipal solid waste.

Large metropolitan areas have experienced especially sharp increases in solid waste disposal costs (8:10). The purchase and preparation of land for new disposal sites, and the increasing hauling distance from metropolitan areas to those sites make up a large portion of the total disposal cost (22:p.10-3). This combination makes solid waste disposal the third largest budget item for many communities.

The Office of Solid Waste Management Programs was established under the United States Environmental Protection Agency (U.S. EPA) in 1971 to address many of the problems involved with solid waste (85:17). Initially, that office emphasized methods of decreasing the volume of solid waste going into landfills. Materials recovery, incineration, and shredding were encouraged as pretreatments to reduce the volume of waste deposited in landfills. These methods can greatly extend the useful life of a landfill, as well as reduce pollution from leachate (45:49). Energy and reusable materials recovered in the process can help offset the disposal costs incurred by local governments and, ultimately, the taxpayer (22:p.10-3).

The oil embargo of 1973 brought a sudden shift of emphasis in solid waste management programs towards energy recovery (8:10). This policy change and the general concern over reliable energy sources was felt throughout the federal government. The national energy policy set forth by former President Carter in 1977 called for reducing this country's dependence on foreign energy supplies (42:7). One obvious way of doing that was to develop alternate fuels from domestic resources, such as refuse-derived fuel (RDF) from our growing supply of solid waste. It was also during 1977 that the Department of Energy (DOE) was formed, and took over much of the responsibility for directing the development of RDF as an alternate fuel from the U.S. EPA.

The Department of Defense (DOD), itself vulnerable to energy supply disruptions, began a cooperative effort with DOE to develop military heating and power facilities capable of using readily available conventional (coal) and alternate fuels. The joint program was designed to regularly exchange energy research information and to jointly support development of new energy technologies related to defense needs (39:3). Densified RDF (dRDF) is one particularly promising fuel for use in military heating plants, and is being studied to determine its ability to meet requirements for reliability, economy, environmental safety, and operating ease in military boilers. The biggest advantages of dRDF are that it can substitute for or supplement coal; it is produced from readily available material which is itself renewable; it has a low surfur content; and its use would conserve limited fossil fuel resources (42:7).

Wright-Patterson AFB (WPAFB) became actively involved in the RDF research and development program in 1975 when a short test (40 ton burn) was conducted using a mixture of coal and dRDF in one heating plant boiler (42:69). The encouraging results of that test, and the Air Force's interest in gathering long-term data on the use of dRDF, resulted in the award of a contract to Teledyne National Corporation in 1979 to provide dRDF for a thirty month evaluation. Under the auspices of the Air Force Engineering and Services Center (AFESC), operating experience gained from burning a 1:1 (by volume) mixture of coal and dRDF under normal load conditions was expected to provide more definitive operating characteristics for widespread use of dRDF. A detailed technical evaluation of dRDF use at WPAFB was conducted by Systems Technology Corporation (SysTech) during April and May of 1981 as part of AFESC's overall research and development program (38:14). The AFESC expects to develop specifications for multiple fuel military heating and power plants from the final results of the test at WPAFB, as well as from similar tests at other DOD installations. Those specifications could then be used to modify existing plants or to build new plants capable of using alternate fuels (refuse, wood chips, biomass; in shredded or pelletized form).

Problem Statement

The price of coal delivered to WPAFB is currently much less than the delivered price of dRDF. However, the opening of an RDF production facility in the Wright-Patterson vicinity, sharp increases in the price of coal, or other events could change that imbalance. Differences in power plant operations and maintenance expenses could also affect the relative costs of using the two different fuels. This thesis explores the question of which fuel will be cheaper to use in the two main heating plants at WPAFB over the next twenty years.

Justification for Study

Studies completed thus far under the RDF Research, Development, Testing and Evaluation Program (RDT&E) have focused on the technical feasibility of using this fuel in full-scale heating plant operations. Table 1 shows the RDT&E studies planned or conducted during recent years in support of the USAF's dRDF development program.

While it is early in the dRDF development program, and information is still being gathered on the technical aspects of its use in military boilers, the cost of using dRDF over the long term has not received as much attention. Presently, WPAFB pays a premium price for the dRDF it is test burning, due to the high transportation costs of this fuel as compared to coal (see Table 2). While this extra cost can be justified in a pilot project to demonstrate feasibility, advance fuels technology, or encourage others to use the new fuel, the large-scale[1] use of dRDF will require that it be more cost-competitive with coal. One compelling reason being that "the American people have a right to expect economical performance of Federal activities [31:1]."

[1]The eventual plan (informal) calls for replacing 25 percent of Wright-Patterson's coal consumption with dRDF. This is roughly equivalent to burning 50,000 tons of the waste-derived fuel annually (37; 69).

TABLE 1

RDF RESEARCH, DEVELOPMENT, TESTING AND EVALUATION (39:15a,17-18)

Bin and Feeder Design for RDF	Jenike & Johanson, Inc., 1979
Thermogravimetric Analysis of RDF and Coal	U.S. Army, CERL, 1979
Control and Disposal of RDF Production Byproducts	SCS Engineers, 1979
Literature Review of Military Scale RDF Use	SRI International, 1979
RDF Combustion Performance Test Procedure	Systems Technology, 1979
Production and Use of dRDF in Military Heating Plants	U.S. Army, CERL, 1980
Study for RDF Production and Use in Military Central Boiler Plant	U.S. Army, CERL
Installation-Scale RDF Processing Analysis	U.S. Navy, Sanders & Thomas, Inc.
Enginering and Design of Conveyors	U.S. EPA, National Center for Resource Recovery, Jenike & Johanson, Inc.
Technology Evaluation for RDF Specification & Acquisition	U.S. Navy, Cal Recovery, Inc.
Technical Efficiency and Environmental Investigation	U.S. EPA (Hazardous Waste)
Management Impact Assessment of RDF Implementation	U.S. Army (Facilities Support)
Performance Analysis of Cofiring dRDF and Coal	U.S. DOE, Argonne National Laboratory, Rycon National Bureau of Standards U.S. DOE
Occupational Health and Safety	U.S. Army, USAF Occupational & Environmental Health Lab

TABLE 2

CURRENT COST OF COAL AND dRDF DELIVERED TO WRIGHT-PATTERSON AFB (69:p.2-1; 11; 46)

Coal (FOB mine)[a]	$40.75	dRDF (FOB plant)	$27.00
Railroad charge[a]	$14.33	Truck charge	$60.80
Total Cost per Ton Delivered	$55.08		$87.80
Heat Content[b] (BTU/lb.)	13,750		6,750
Cost per MBTU	$ 2.00		$ 6.50

[a]Average costs for equal size purchases from two coal suppliers: Pittston and Tricentenial.

[b]See Appendix B for details of fuel characteristics.

A local source of dRDF would change the cost comparison considerably, but future prices and availability of different fuels are not the only factors in determining which fuel will cost the least to use over the long term. Operations and maintenance expenses over a twenty-year period could move the cost advantage from one fuel to the other, despite countervailing differences in basic fuel prices. Several problems have already been noted by researchers and heating plant employees in the use of dRDF, but whether or not operating expenses will be higher for using dRDF than for using coal is still unknown. The additional man-hours required for handling dRDF, the higher levels of dust around machinery, boiler slagging, and reduced electrostatic precipitator efficiency are all aspects of dRDF use that could affect the cost comparison of using this alternate fuel or coal.

Research Objectives

Scope

This study is limited to a consideration of the two main heating plants at WPAFB, burning either coal, or a mixture of coal and dRDF in varying proportions.

Hypothesis

Coal will be less expensive to use in the object plants under the most likely conditions prevailing in domestic fuel markets over the next twenty years, than dRDF or a mixture of coal and dRDF.

Research Questions

The research questions posed for this study are:

1. What will be the heating demand on the two main plants over the next twenty years?

2. What will be the future price of different grades of coal which may be burned at Wright-Patterson AFB?

3. What will be the future price of dRDF and its composition?

4. What will be the future truck and railroad ton-mile transportation rates?

5. What will be the overall plant maintenance cost of using coal to heat WPAFB?

6. What will be the overall heating plant maintenance cost of using dRDF or a coal/dRDF mixture to heat WPAFB?

Assumptions

Assumptions concerning the environment in which the heating plants will be operating are as follows:

1. Wright-Patterson AFB will continue operations at a level similar to its present activity, over the time span considered in this study. (The mission, population, and heating requirement will not change drastically.)

2. The two main heating plants now providing most of the heat for WPAFB will not be replaced or radically modified during the next twenty years.

3. A presently unknown fuel will not replace coal as a common boiler fuel.

4. Current state and federal EPA regulations for stack emissions and waste disposal will not be abandoned.

5. Coal and dRDF will both be available for purchase under government contract, and in quantities large enough to meet the heating requirements of WPAFB.

6. Railroad transportation for movement of bulk-type commodities will be available for the next twenty years.

7. The American economy will remain in a situation of increasing prices, with general inflation between 1 and 20 percent annually.

Additional assumptions concerning specific parameters and functional relationships of the cost model developed as part of this thesis are included in applicable sections, primarily in Chapter IV.

Plan of the Report

The background and research objectives for this study have been presented in the introductory chapter. Chapter II reviews energy recovery, facilities using or planning to use RDF, previous dRDF tests, and experience gained from dRDF use at WPAFB. The methodology chapter outlines the steps used to describe and model the heating plants. Chapter IV details the parameters and relationships used in formulating the model. Computerization of the model is also described there. The simulation experiments that were conducted are explained in Chapter V, and the final chapter summarizes the results of those experiments. Conclusions, recommendations, and related observations are also included in Chapter VI. Much of the related material used in building the model is contained in the appendices, along with a glossary of terms used throughout the report.

CHAPTER II

LITERATURE REVIEW

Energy Recovery Methods

There are two primary methods for recovering energy from solid waste. Mass burning is the most common, and produces steam by burning unprocessed solid waste in specially designed waterwall boilers (58). Several large cities in Germany have used this type of steam generating incinerator since the early 1960s, as have other cities throughout Europe (29:D-9). In the United States, similar operations began with the plant in Hampton, Virginia in 1967. Among the larger mass burning plants operating today are those in Saugus, Maine; Harrisburg, Pennsylvania; Chicago, Illinois; Nashville, Tennessee; and Norfolk, Virginia--all of which provide process steam to nearby industrial plants, government facilities, or downtown buildings (58). Burning processed fuel is the other primary method of energy recovery from solid waste. Rather than burning the refuse just as it comes off the collection truck, this second method sorts and refines the waste to produce a fuel better suited for use in the type boilers presently found in many municipalities, institutions, and manufacturing companies.[1]

[1]Using processed refuse as a substitute for stoker coal has wide applicability, since nearly half of the roughly 42,000 industrial boilers in the United States are coal-fired (24:iii).

Underlying these two methods are two distinct orientations. The mass burning operations were developed to reduce the volume of trash that had to be disposed of in landfills. Over the last decade the additional advantage of steam production for area heating as a byproduct of mass burning has been recognized and exploited by some organizations in this country. The major objective in burning processed solid waste, however, is to produce energy for heating or power generation. Organizations pursuing those activities are interested in high quality fuels which can be burned economically in existing equipment. The use of RDF at Wright-Patterson AFB falls in this second category, and is the area that will be focused on throughout this thesis. The practical significance of the distinction is that optimizing the objectives of waste incineration and power production simultaneously, under cost constraints, will likely result in a facility or operation that does a mediocre job of both (72).

Refuse-Derived Fuel

The general term for fuel produced by processing solid waste is refuse-derived fuel (RDF). Interest in producing and using RDF has been sparked in this country by rising solid waste disposal costs, environmental restrictions on disposal sites, and escalating energy costs (58; 41:9; 84:ii). Several facilities currently producing RDF in the United States, or expected to go into operation, are listed in Table 3. As might be surmised from the handful of facilities actually in operation among those listed, RDF production is still a very young industry in this country.

The process used in making RDF removes much of the nonburnable material from the solid waste stream (58). Typical separation methods are air classification, magnetic separation, and screening. More advanced procedures such as froth flotation and eddy current separation can remove much of the glass and aluminum remaining after the initial processing steps are completed. While many of the inorganic items removed during the processing (sand, rocks) must be trucked to the landfill for final disposal, the various metals and glass separated during processing may be recycled. The recovery of such recyclables can help offset the cost of operating the RDF production plant if a ready market exists for the materials (58). To further enhance the burnability of the combustibles, the solid waste is also shredded so the resulting fuel has a more uniform size. Figure 1 shows a generic RDF production system. The output from the air classifier is coarse RDF, with a particle size averaging six inches or less (41:45). Secondary shredding produces fluff RDF (one inch and less), and additional processing steps are needed to produce densified RDF or dust RDF.

TABLE 3

SOLID WASTE PROCESSING FACILITIES FOR RDF PRODUCTION (62)

Location	Process	Products	Status
Bridgeport, CN	Sh,Ac, Mg	Eco-Fuel II (patented dust RDF)	Temporarily closed due to company financial difficulties
Wilmington DL	Sh,Ac	RDF, ferrous & non-ferrous metals, glass, humus	Under construction (1982 start-up)
Lakeland FL	Sh,Mg	RDF (to burn with coal for steam-electricity production)	Under construction (1981 completion)
Honolulu HI	Sh, Mg, Sc	RDF (used for steam in processing cane and producing electricity)	Contracts finalized
Chicago IL	Sh,Mg	RDF for local utility, ferrous metals	Off-stream to evaluate future operations
Ames IO	Sh,Ac, Mg,Sc, Mc	RDF for county utility, baled paper, ferrous & non-ferrous metals	Operational
Baltimore MD	Sh,Ac, Mg,Mc	Shredded and Pelletized RDF, ferrous metals, glass	Operational
Haverhill Lawrence MA	Sh,Ac Mg,Mc	RDF (steam & electricity for local utility and industries)	Under construction (1984)
East Bridgewater MA	Sh,Ac, Mg,Mc	Eco-Fuel II and Eco-Fuel briquets for industrial boilers	Presently closed due to financial difficulties (previously the Eco-Fuel pilot plant)

TABLE 3--Continued

Location	Process	Products	Status
Detroit MI	Sh,Ac, Mg	RDF for Detroit Edison boilers	Contract Nego- tiation, Bond Issue
Duluth MN	Sh,Ac, Mg	RDF for steam heating- cooling-process equip- ment, ferrous metals	Shakedown, operational late 1981
Newark NJ	Sh,Ac, Mg,Mc	Eco-Fuel II for local utility, ferrous metals, aluminum	Contract signed and site preparation com- plete
Albany NY	Sh,Mg	RDF, steam for urban heating and cooling, ferrous & non-ferrous metals	Processing plant opera- tional, steam plant in shake- down
Hempstead NY	Mg,WP	RDF for local utility, glass, aluminum, ferrous metals	Temporarily shut down pend- ing USEPA establishment of dioxin standard
Monroe County NY	Sh,Ac, FF,Mg	RDF for local utility, ferrous and non-ferrous metals, glass	Shakedown status
Niagara Falls NY	Sh,Mg	RDF for Hooker steam and electricity, ferrous metals	Expected operational late 1981
Akron OH	Sh,Ac, Mg	RDF for urban and indus- trial steam heating and cooling	Operational
Columbus OH	Sh,Mg	RDF for city steam generated electricity	Under construc- tion (expected operational late 1981)

TABLE 3--Continued

Location	Process	Products	Status
Lane County OH	Sh,Ac, Mg	RDF, ferrous metals	Negotiating with contractor regarding acceptance as operational
Portsmouth VA	Sh,Ac, Mg	RDF for Naval Ship-yard power plant, ferrous & non-ferrous metals	Contract approval process (operational 1986)
Tacoma WA	Sh,Ac Mg	RDF, ferrous metals	Operational
Madison WI	Sh,Mg, Sc	RDF burned by city utility, ferrous metals	Operational
Milwaukee WI	Sh,Ac, Mg	RDF for local utility, baled paper, ferrous metals	Operated during 1980. Temporarily shut down pending negotiations with WI Electric Power Company

Process Key: Sh-shredding, Ac-air classification, Mg-magnetic separation, Mc-mechanical separation, Sc-screening, FF-froth flotation, WP-wet pulping.

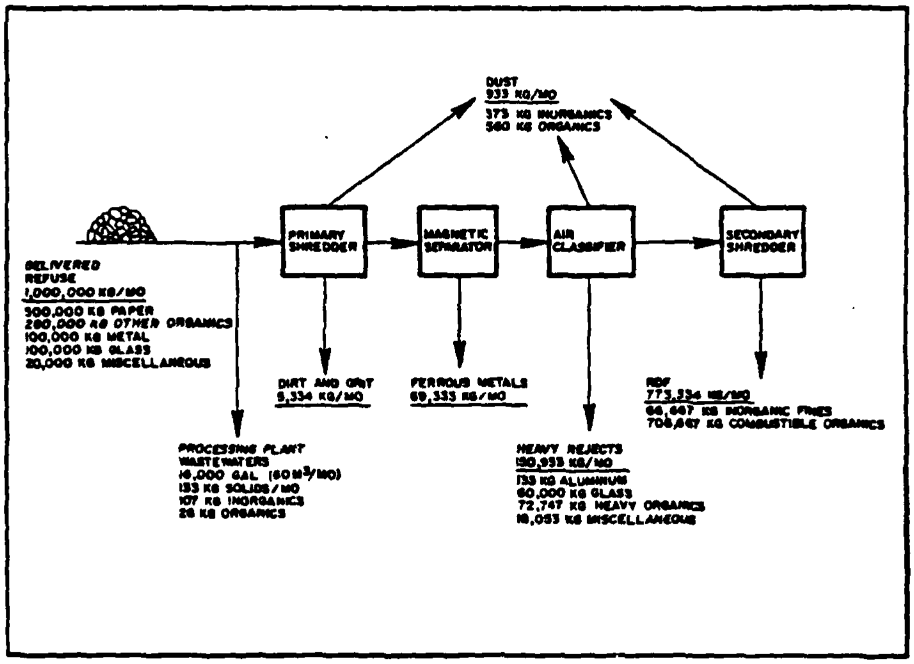

Fig. 1. Generic Refuse-Derived Fuel Production Process [40:9]

RDF can be used as a supplement to or substitute for fossil fuels in boilers. Coal is most often the fuel supplemented or replaced, but facilities have co-fired RDF with oil or natural gas. With those two fuels, however, the existing boilers usually do not have enough ash-handling capability to co-fire RDF. In any case (with coal, oil, or natural gas), modifications to the boiler or to operating procedures are required because the RDF differs in many characteristics from the fossil fuels for which most boilers were originally designed. Capital improvement costs may be incurred, and a change in operating expenditures may result when RDF is burned in existing boilers (58). The similarities of coal and dRDF, however, help minimize equipment alterations when co-firing these two fuels.

Densified Refuse-Derived Fuel

The densified form of refuse-derived fuel (dRDF) holds considerable promise as a renewable alternate fuel for military heating and power plants. A major reason for this is that "the military coal conversion effort will emphasize conventional coal combustion technologies. . . . [42:7]." That trend is clearly evident in the fiscal year 1980 and 1981 Military Construction Program budget for the Air Force, where funding was authorized for new coal burning plants at Arnold Engineering Center, Fairchild AFB, and F. E. Warren AFB (9). Included in plans for those plants, as well as for modifying existing plants, is the requirement under the USAF Coal Conversion Program to design for alternate fuel use where feasible (1:6B1). That reference to alternate fuels includes wood, biomass, and refuse-derived fuels.

The densified form of RDF can be used as a direct substitute for coal, though early evaluations have shown that a mixture with coal is easier to use (42:69). The dRDF used at Wright-Patterson AFB was produced by compacting and extruding fluff RDF through a mechanical die, forming dense pellets approximately one and one-half inches long by one-half inch in diameter. These pellets can be mixed with coal and handled reasonably well by many present fuel conveyors and feed bins. Other tests of dRDF have used different size pellets, briquets made from dust RDF, and RDF cubettes made with an alfalfa cuber (24:207). A list of dRDF test burns conducted in this country since 1970 is shown in Table 4. As of September 1980, Wright-Patterson AFB was the only DOD facility burning dRDF (49).

A review of those previous tests conducted under the sponsorship of the Army Civil Engineering Research Laboratory (CERL) found ". . . little scientific design in the conception and conduct of the experiments [42:75]." The authors of that report criticize the "hit or miss" approach to fuel substitution that dominates the RDF industry, the lack of monitoring equipment used in field testing RDF, and the scarcity of written reports on the tests that have been conducted (42:77). They recommended a multi-year commitment of resources, with inquiries into the storage and handling properties, the combustion characteristics, and the environmental consequences of using dRDF (42:78). The results of such research could be used in adjusting and modifying existing equipment for reliable, long-term use of dRDF or coal:dRDF mixtures.

TABLE 4

SUMMARY OF dRDF TESTS (42:69-70)

Location	User	Sponsor	Date	Boiler Description	Material Quantity and Description	Producer	Comments
Fort Wayne, IN	Fort Wayne Mun. Power Co.	Fort Wayne	1972	Underfeed-multiple retort	40 T 1 1/2 in. x 1 1/2 in. x 2 in. cubets	National Recycling Corp.	3:1 by vol. (?) 6850-8530 Btu/lb Roy F. Weston
Eugene, OR	Eugene Water & Electric Board	Eugene W&E	10/74	155 M lb/hr traveling chain grate-spreader stoker	21 T 3/8 in. pellets 105 T fluff (from St. Louis)	Vista	Sandwell International five 6 to 7 hour tests
Appleton, WI	Consolidated Paper	Wisconsin Solid Waste Recycling Authority	5/76, 10/76	52 M lb/hr modified for gas; tested with gravity feed, manual ash removal	40 T 3/4 in. pellets	Grumman	Market development test
Waupun, WI	Waupun State Prison	Wisconsin Solid Waste Recycling Authority	6/76	35 M lb/hr spreader stoker-vibragrate	20 T 3/4 in. pellets	Grumman	20-30-40% pellets by heating value Market development test
Oshkosh, WI	U. of Wisconsin	Wisconsin Solid Waste Recycling Authority	11/76	45 M lb/hr spreader stoker-vibragrate gas or coal	20 T 1 1/8 in. pellets 27 PCF density	Vista	1:1 & 1:2 blends Market development test
Green Bay, WI	Fort Howard Paper	Wisconsin Solid Waste Recycling Authority	11/76	275 M lb/hr B&W spreader stoker	40 T 3/4 in. pellets	Grumman	1:3 & 1:2 blends Market development test
Menasha, WI	Menasha Paper Board	Wisconsin Solid Waste Recycling Authority	10/76	165 M lb/hr spreader stoker	20 T 3/4 in. pellets	Grumman	3:2 blend Market development test
Stockertown, PA	Hercules Cement	Unknown	4/75	Cement kiln	Reground 200 T 1 1/8 in. & 5/8 in. pellets	Vista	7 day test – problems in regrind with existing pulverizers
Sunbury, PA	Pennsylvania Power & Light	Unknown	5/75	Suspension fired utility boiler	Reground 80 T 5/8 in. pellets	Heiki Elo	2 day test

TABLE 4--Continued

Location	User	Sponsor	Date	Boiler Description	Material Quantity and Description	Producer	Comments
Piqua, OH	Piqua Mun. Power Plant	Unknown	6/75	150 M lb/hr C.E. chain grate, gravity overfeed	22 T 3/8 in. pellets	Black Clawson	1:1 vol.; 6400 Btu/lb Franklin pulp product dried and pelletized
Dayton, OH	Wright-Patterson A.F.B.	Air Force	7/75	80 M lb/hr traveling grate–Detroit spreader stoker	40 (?) T 3/8 in. pellets	Black Clawson	34 hr 1:1; 6 hr 1:2 Product as above
Rantoul, IL	Chanute A.F.B.	Air Force, Army	9-10/75	35 M lb/hr traveling chain grate–gravity overfeed	150 T 1 1/8 in. pellets	Vista	1:1 & 0:1; 4 box cars Material degraded in transit and long storage
Hagerstown, MD	Maryland Correctional Institute (M.C.I.)	EPA	3,5/77	60 M lb/hr Erie City spreader stoker	280 T 1/2 in. pellets	NCRR	58 hr 1:1; 53 hr 1:2; 29 hr 0:1
Hagerstown, MD	M.C.I.	Maryland Environmental Services (M.E.S.)	Fall/78	As above	250 T 1/2 in. & 1 in. pellets	Teledyne	3 test burns over couple months
Spring Grove, PA	P. H. Glatfelter Co.	M.E.S.	Fall/78	Small bark boiler	100 T 1/2 in. & 1 in. pellets and some fluff	Teledyne	Market development test
Maryland–5 Locations	Institutional Boilers	M.E.S.	1977-78-79	Five 10 M lb/hr boilers	<20 T 1/2 in. & 1 in. pellets each test	Teledyne	Market development test
Not revealed	Not revealed	Private	1977	50 M lb/hr underfeed stoker	<25 T 3/8 in. & 5/8 in. pellets	Heiki Elo	Up to 100% pellets Market development test
Not revealed	Not revealed	Private	1978	150 M lb/hr overfeed stoker	<25 T 5/8 in. plant waste pellets	Heiki Elo	Market development test

TABLE 4--Continued

Location	User	Sponsor	Date	Boiler Description	Material Quantity and Description	Producer	Comments
Vestal, NY	Harper College	Raytheon/State of NY	11/70	100 M lb/hr vibra-grate–mass feed stoker	25 T 1 in. pellets	NCRR	0:1 & 1:1 blend; burn-back; degraded pellets - jams Market development test
Washington, DC	GSA-Virginia Heating Plant	DOE/GSA	3/79	70 M lb/hr underfed multiple retort	125 T 1/2 in. pellets–office wastes	NCRR	30 hr 4:1; 30 hr 2:3; 90 hr 3:2; 6600 Btu/lb
Erie, PA	General Electric	EPA	3-4/79	125 M lb/hr spreader stoker	2000 T 1/2 in. pellets	NCRR 700 T Teledyne 1300 T	
Dayton, OH	Wright-Patterson A.F.B.	Air Force	5/79-10/81	80 M lb/hr spreader stoker–traveling grate	±70000 T 1/2 in. pellets	Teledyne	Contract for $27/ton F.O.B. plant, transport ±30/ton; 1:1 vol. ratio, Promotion of DRDF alternate fuel sources

Experience with dRDF at Wright-Patterson AFB[2]

A thirty-month test at WPAFB was undertaken to evaluate the long-term feasibility of using dRDF in military heating plants. This test was to support the "multi-year commitment of resources" for development of dRDF as a military boiler fuel. The information accumulated was to be used to set specifications for fuel purchases, boiler modification, and operating procedures for future use of dRDF (42:73). Specific areas for investigation during the Wright-Patterson test were dRDF storage and handling, fuel specification evaluation, boiler efficiency, air pollution, corrosion, and impact on plant management.

Transportation of dRDF

The first deliveries of dRDF for this test arrived by truck in May 1979. The next several shipments came by rail. Though shipping charges were less than half as much per ton for rail ($23 versus $55), difficulties in unloading the railcars and greater deterioration of the pellets during transit made truck transportation the preferred method of shipment. Special railcars were even employed to protect the fuel pellets during shipping (top covers) and to improve unloading (chute modifications). The combination

[2]Most of the information presented in this section is a summarization of four "RDF Status Reports" compiled by Mr. Thomas Shoup of the 2750th Civil Engineering Squadron Environmental Planning Branch, during the period May 1979 to September 1980.

of long travel times, a jarring ride, and moisture condensation caused the dRDF to clump together so that it would not flow out of the railcar dump chutes. Hand shoveling and rodding were required to unload the car, which required more manpower and posed greater risks to those workers. Subsequent deliveries of dRDF to WPAFB were made by truck, which presented no large unloading problem.

Fuel Quality

The quality of the dRDF in early deliveries, whether by rail or truck, was marginal. Instead of the 5 percent maximum fines (unpelletized material) by weight specified in the contract, percentages three and four times higher were noted in two hand samples. A contract was let for laboratory analyses of the dRDF deliveries in January 1980, to determine whether or not contract specifications were being met. Part of the problem of poor quality was caused by pellet disintegration during shipping, and there was an improvement when the producer (Teledyne National Corporation) began shipping fresh pellets instead of the two-month old pellets stockpiled at their facility. To further reduce the fines leaking into the shipments to WPAFB, a vacuum hood was installed over the pellet mill discharge conveyor to collect fluff and dust.

Despite the improvements, dRDF received at WPAFB still included high levels of fines and failed to meet certain specifications on a regular basis (see Appendix C). The major reason for the marginal fuel quality seemed to be the lack of moisture controls on Teledyne's pellet production process. Wet garbage (from rain--beyond their control) causes high moisture content, high fines, and low energy content in the dRDF. New RDF production plant designs include a dryer before the pellet mill, but at Teledyne in Maryland when the trash gets too wet they usually stop production and wait for dry weather.

Handling and Mixing dRDF

The same factors causing difficulty in railcar unloading caused plugging in the storage silos initially. As little as two days in the silos resulted in plugging that required additional labor to clear. When better pellets were received, however, this problem was considerably alleviated. Though some rodding is needed to start the flow when dRDF has been stored for more than three days, the improved pellet quality obviates the need for additional effort once the material has started flowing.

The best method for storing dRDF at the heating plants seems to be to mix it with coal immediately and load the mixture into a storage silo. The computerized fuel handling system is capable of doing this, but appropriate instructions have not been programmed. The practice so far has been to store the dRDF in one silo and coal in the other three.

The two fuels are blended by loading coal and dRDF on the same conveyor out of the storage area. The early silo-plugging problem caused surge feeding of dRDF onto the conveyor. This made for an uneven coal:dRDF mixture going into the bunkers that feed the boilers. Again, improved pellet quality rectified the situation so a more constant fuel ratio could be fed to the boilers.

The dust generated during dRDF handling brought complaints from heating plant employees, especially when dry loads were received. A medical evaluation of RDF samples from WPAFB by the USAF Occupational and Environmental Health Laboratory (OEHL) found no significant hazard, but heavy dust fall and odors from dRDF handling continued to irritate plant employees. The fluff and linty dust coming from dRDF handling also created more housekeeping chores (or the need thereof) to keep the plant clean.

Combustion of dRDF

Smoking was encountered at high boiler operation levels, seemingly due to an uneven ash bed across the boiler grates. The fines burning in suspension and the faster grate speed resulted in channeling of forced air to the rear of the boiler, and the insufficient combustion air to the middle and front grates created smoke. Air adjustments and a lower percentage of fines were expected to correct this problem. Below 50 percent capacity, good boiler control was maintained. A constant coal:dRDF ratio appeared to be very important for smooth boiler operation.

The lower ash fusion temperature, higher flame temperature, and glass content of dRDF (compared to coal) were suspected of causing ash bed clinkers. This required the boiler operator to use the "ash hook" more often to reach in and break up the clinkers and avoid possible damage to the boiler grates.

Also presumably because of the glass found in municipal solid waste (and consequently the dRDF), some deposition occurred on the rear wall of the boiler used during the 1975 test burn. If allowed to build up these deposits could block air ports, leading to boiler damage, as well as reduce boiler efficiency. A recent summer inspection (July 1980) showed no deposition or slagging problems with the boiler tubes or refractory, but did reveal some deposition on a plate leading to the stoker paddles. Plastic in the fuel evidently adhered to the warm plate, building up to one-half inch. The deposit may not increase beyond that point (without intervention) because it insulates the plate from the fuel flow, but it will have to be monitored because it decreases the fuel flow to the stoker.

Summary

As of the 30 September 1980 status report, boiler operation and performance were considered good, though some difficulties in handling dRDF were still being experienced. Those difficulties were attributed to the quality of dRDF received at WPAFB, which varied considerably from one shipment to another. Another attempt at railroad transport of dRDF was also being made, in hopes that coal cars with large chutes and top covers would be suitable and thus reduce the high shipping costs presently being paid for the refuse-derived fuel.

CHAPTER III

METHODOLOGY

Overview

The objective of this study is to explore the effect of different combinations of coal and dRDF on heating plant operating costs. The operating costs of heating and power plants usually vary with the amount of energy produced (71:546). For the plants at WPAFB, the heated water or steam represents the energy produced, and the magnitude of energy produced is adjusted regularly to meet the heating demand of base facilities. Since there is a direct relationship between outdoor temperature and heating demand (see Appendix D), the yearly operating costs also reflect the local weather conditions during that period.

The cost of construction and past modifications to the WPAFB heating plants will not be considered in the analysis since they are sunk costs.[1] The focus is instead on attaching costs to those items of operating expense that vary with the heating demand. While total operating

[1]Activities under a program to reduce the central heating facilities at WPAFB from five plants to two plants (with accompanying economies) began in FY 72 (51:1). That $37 million project brought the remaining coal-fired plants into compliance with air and water pollution standards (38:14). The automated handling equipment and storage silos included in the project were also expected to aid in handling and storing alternate fuels such as dRDF (50).

expense varies widely with type of plant, output, and geographical location, experience in civilian heating and power plants up to 1960 has shown the range of percentages for different components of total operating cost listed in Table 5. Review of Fiscal Year 1980 (FY 80) accounting records for two local institutional heating systems (Appendix E) shows a certain resemblance to the older figures (if it can be assumed that expenses for various items are tallied under the same general headings from then to now). Oil and natural gas heating plants incur high fuel cost and low labor costs in relation to Table 5 percentages, while coal plant fuel and labor costs are just the opposite. This is so because coal prices have been lower than oil prices, making fuel costs a lower proportion of the total cost when coal is used (80:46). The larger labor force needed to operate a coal-fired plant puts their labor expenses on the high end of Table 5 direct labor percentages.

To compare future heating plant operating costs at Wright-Patterson AFB under conditions such as different fuel combinations, a cost model of the base heating system was developed. Answers to the research questions (obtained through literature search and interviews of experts) provided the input data for the model. (The model will be introduced later in this chapter.) The projected costs of future year operations are computed and converted to present

TABLE 5

RANGE OF OPERATING EXPENSE COMPONENTS FOR CIVILIAN HEATING AND POWER PLANTS (71:563)

Component	Percentage of Total
Fuel	75-85%
Direct Labor	5-15%
Maintenance Labor & Materials	5-20%
Supplies	1- 5%
Supervision	1- 2%
Operating Taxes	0-10%

values within the model, and summed for a twenty-year period. The total present value of heating plant operating costs will also be tested for sensitivity to changes in selected parameter values, since estimates for some of those parameters are uncertain and may significantly affect the results obtained from the cost model. It is expected that use of this model will improve understanding of the heating plant operating costs, as well as provide cost projections for setting budgets and comparing alternatives for plant operation.

Modeling

A model is a representation of a process or system (81:4). The model built for this study represents the major components of the Wright-Patterson AFB central heating system necessary for estimating the yearly operating cost for the heating plants.

Models often have a manipulatable structure, making it possible to observe their response under various assumptions and key relationships (81:4). It must be remembered, however, that the responses being observed are from the model and not from the actual system being represented (19). A clearer understanding of the object system can be gained through experiments with the model, but caution must be used in ascribing the experimental results to those of the real system. Ideally, the model should be thoroughly validated by comparing its response under identical conditions to actual events before using the model results to formulate policy or make decisions (81:4).

The process of modeling can be divided into several steps. Describing the problem, setting objectives, and stating assumptions are the first steps. Choosing characteristics or elements from the original system or process, developing the mathematical relationships between them, and gathering data to use in running the model follow. An expanded list of those steps is contained in Appendix F. The end results from conducting experiments with a model would commonly be recommendations for a decision maker to act on (81:4-5).

System Definition

The WPAFB central heating system can be characterized using an input-processing-output configuration as shown in Figure 2. The inputs consist of such things as coal, the man-hours needed to run the plant, maintenance and repair activities, make-up water, electricity, anti-corrosion chemicals, and lubricating oils. The processing that occurs combines the resources to produce heat energy for the base "customers." Residual products of the process are waste heat, stack emissions, and ash that is collected and disposed of in an on-base landfill.

INPUT	→	PROCESSOR	→	OUTPUT
(Resources)		(Heating Plant)		(Heat & Residuals)

Fig. 2. General System Diagram

A more detailed drawing of the central heating system for WPAFB is shown in Figure 3. The boundary within which costs will be accumulated is the heating plant; things entering or leaving the plant affect the operating cost.

Model Formulation

The model developed of the heating plant was intended to capture the significant costs involved in plant operation. These costs are driven first by the heating demand of the base, and secondly by market factors for the

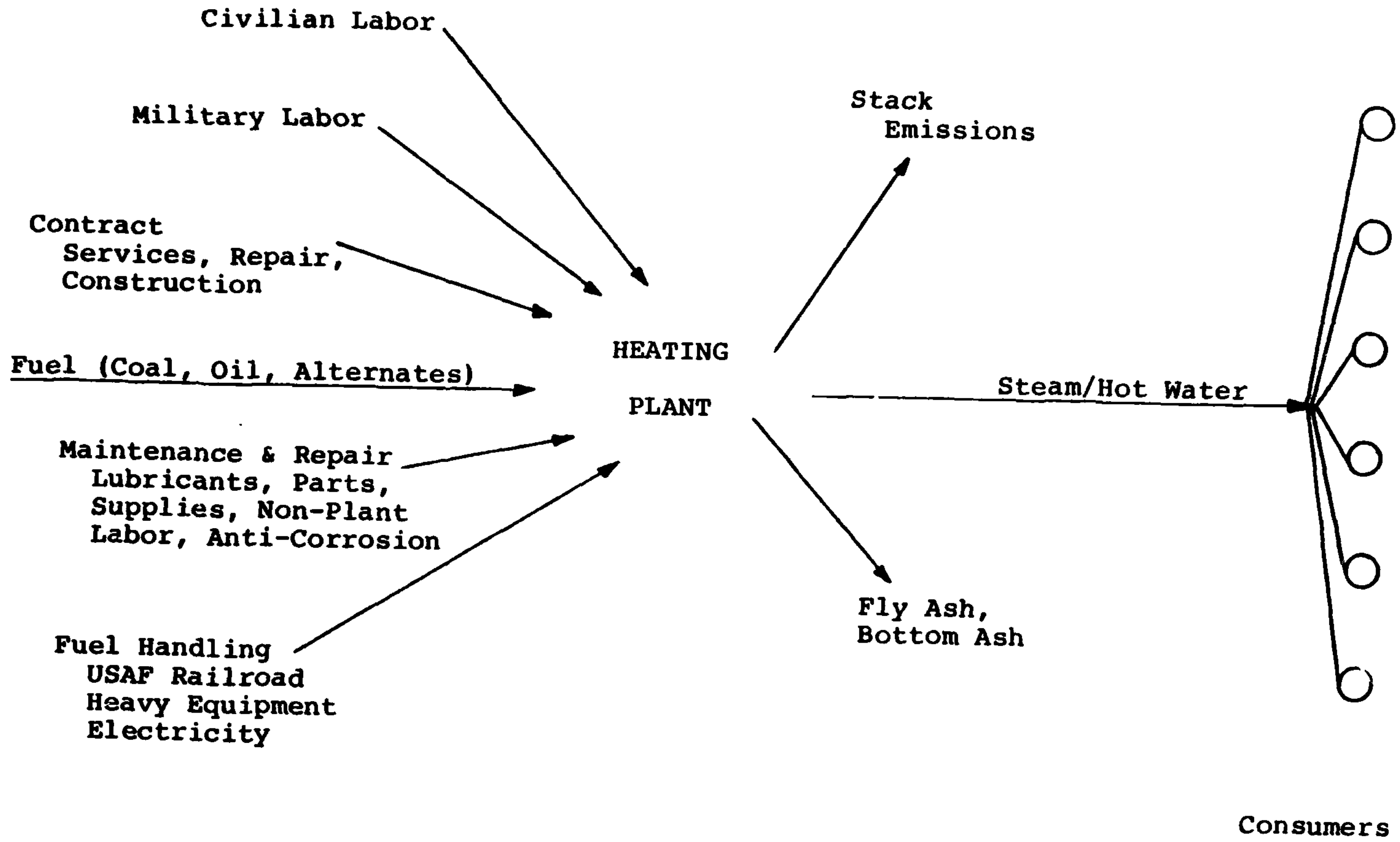

Fig. 3. Base Central Heating System

resources. Management decisions on how those resources are selected and used can also have a significant effect on operating costs. Figure 4 illustrates the components of the economic model and the connections between those components.

The three cost components chosen for this model are fuel, transportation of the fuel, and operation and maintenance. Fuel purchases typically make up the largest portion of total operating cost (Table 5). Transporting the fuel from the mine or production facility to the heating plant is often a significant expense as well (80:81). (The situation described in Table 2 shows that the transportation costs for coal and dRDF to WPAFB are 35 percent and 225 percent of the basic fuel cost, respectively.) Operation and maintenance cost elements for coal and dRDF aggregate the various input resources (except fuel) to the heating system, that were listed separately in Figure 3. Combining the labor, repair, utilities, etc., into one component simplifies the model while still retaining its total cost accuracy.

The driving force for the three cost components is the demand for heat placed on the heating plants. That demand is determined by the size of the space being heated, the resistance to heat flow out of that space, and the temperature differential across the space's boundary. (Modern building design also considers the interior heat

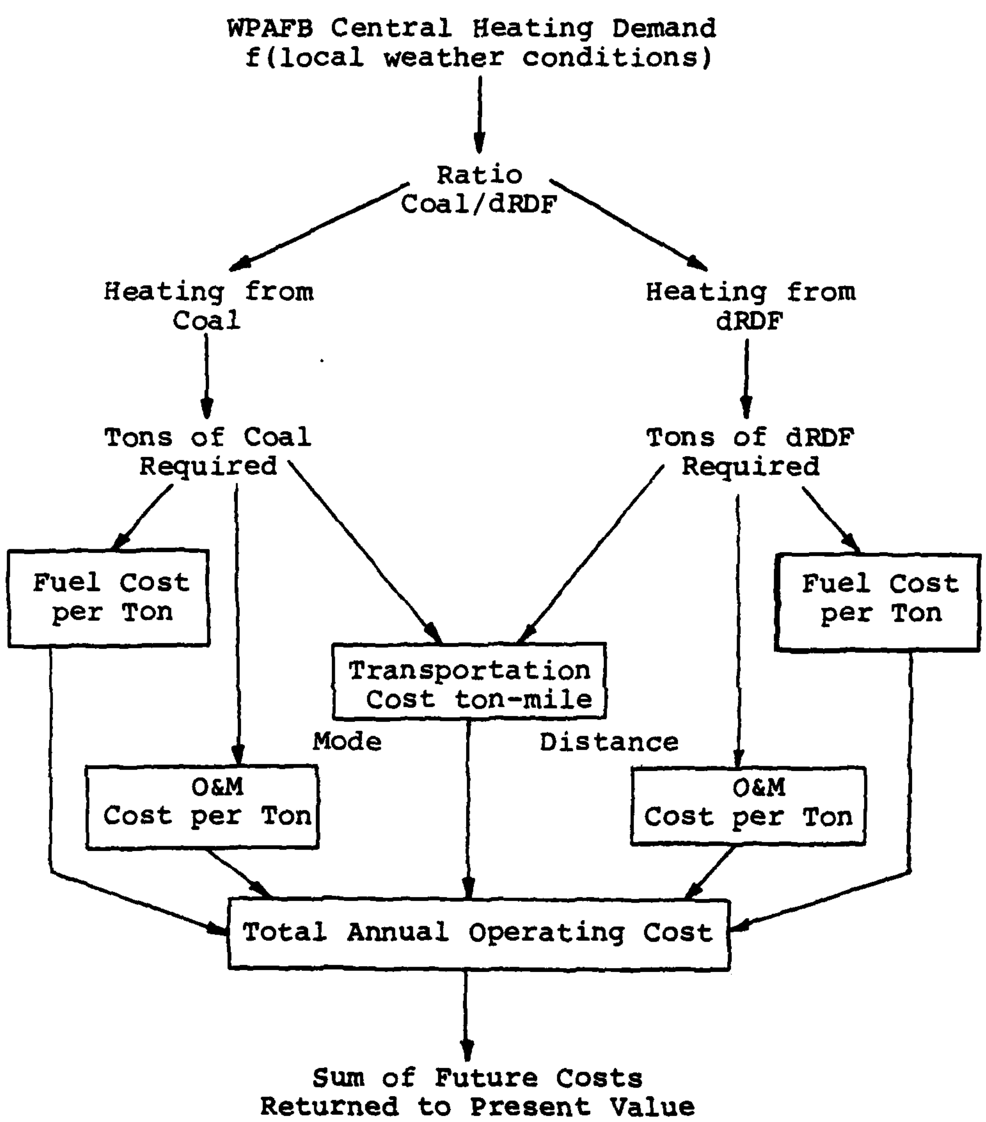

Fig. 4. Heating Plant Operating Cost Model

gain from solar energy, workers or inhabitants, lighting, office equipment, machinery, appliances, anything generating a significant amount of heat--all of which can decrease the space heating demand made on the central heating plant.) Since the total floor space being heated by the two main heating plants at WPAFB is expected to increase slightly in the coming years (37; 51), counteracted by improved energy efficiency in the new buildings (75:5), the dominant factor in heating demand in this case is the outside temperature.

The fuel ratio allows a choice to be made in how much of each fuel is used to meet the base heating demand. The percentage of each fuel used to meet a specific year's demand is converted to tons of fuel (the common unit of measurement for coal and dRDF) which becomes the input to the cost calculations. The base-year fuel, transportation, and operations and maintenance expenses are multiplied by fuel tonnages and future inflation rates to arrive at a yearly cost for each component.

The final part of the model sums the three cost components, and uses a present value factor to show what the value of a future year's expenditure would be today. The present values for twenty years of operating costs are added, and this total present value represents the operating cost of the heating plant for the entire period, under the chosen set of circumstances.

Data Requirements

Much of the data used in constructing the cost model came from historical records. For estimates of future prices and inflation, however, expert opinion was a large contributor. Listed below are several prominent sources of data that were utilized for this thesis.

WPAFB Weather	Heating Degree Days from the Base Weather Shop and USAF/ETAC (Air Weather Service)
Fuel Consumption & Energy Production	Heating plant operating logs, Buildings 1240, 770, 271, 170, 66
Heating Content of Coal and dRDF	Laboratory analyses from the Bureau of Mines and Howard Labs
Current Price of Coal, dRDF, and Transportation	WPAFB Contracting Office; Teledyne production facility; Conrail Freight Quotations Office
Operations and Maintenance Costs	Cost Accounting Branch, 2750th Civil Engineering Squadron; Heating Plant Cost Report, Dayton VA Medical Center
Inflation Rates for Fuel, Transportation, Operations and Maintenance	Bureau of the Census "Statistical Abstract of the U.S., 1980;" AFR 173-13 "Cost and Planning Factors Guide;" NBS-135 "Life Cycle Cost Manual;" DOE "Energy Information Administration Annual Report to Congress 1980;" National Coal Association; American Assn. of Railroads; Coal-Utilities Cost Model (ICF)

Experimental Design

Several experiments were conducted with the heating plant cost model to compare the total present value operating costs for differing conditions in the coal:dRDF ratio, the three cost components, and their inflation rates. The cost used for comparing alternatives was the average of several computer runs with identical cost conditions but under typical weather variations. Parameters tested to determine the sensitivity of this model included the price inflations for coal, dRDF, transportation, and plant operation and maintenance; the heating content of each fuel; the shipping distance; and the discount rate. A detailed description of each individual experiment and the scenario it is attempting to simulate is given in Chapter IV.

CHAPTER IV

THE MODEL AND ITS ELEMENTS

Level of Aggregation

There are two central heating plants at Wright-Patterson AFB. One supplies steam to customers on one portion of the base, and the other supplies high temperature hot water both to customers directly and through steam conversion stations for other portions of the installation. The similarities in size, MBTU output, installed equipment, and fuels capability are used as justification for treating the two as a single facility in the model. This simplification is reasonable from the standpoint that the plants have almost identical fuel handling systems; both presently use coal as a primary fuel; both have used dRDF in the past; and both could burn dRDF in the future.

The numerous buildings served by the heating plants are also combined, so that the situation modeled is of a huge boiler providing heat to a single very large customer.[1] Since the objective is to explore the total operating expenses, these two assumptions are appropriate, and avoid unnecessary detail in model formulation.

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[1]This aggregation corresponds to the way costs are accumulated for heating operations by the 2750th Civil Engineering Squadron Cost Accounting Branch, using the Base Engineer Automated Management System (BEAMS).

Variables

The Input Variable

The input variable for this cost model is the projected yearly heating degree days (HDDs) for a twenty-year period at WPAFB. The series of HDDs was developed from the historical listing shown in Appendix G. A frequency distribution of those HDDs was found to fit a Normal distribution, which is randomly sampled to simulate yearly heating requirements. This weather distribution determines the heating demand placed on the heating plants annually (research question number 1). The past record of HDDs was also checked for randomness, with one test showing no trend while another indicated a slight trend towards colder temperatures since 1950. For this model, however, that possible trend was disregarded because many experts in meteorology have not been able to confirm such a long-term weather trend as yet (12).

The Output Variables

The output variables for a single run of the model are the present-day values of the yearly fuel, transportation, and plant operation and maintenance (O&M) expenses. Added together, they become the total operating cost of the heating plants for a twenty-year period, displayed as a single present value. Combining a series of future outlays into one output number in this way was chosen to allow easy comparison of total operating expenses under a selected set of operating assumptions. The full cost of the heating plants includes the yearly repair and maintenance on the buildings themselves. It was assumed that those expenses would not be affected by the type of fuel used inside the plant, and so were ignored for the comparison.

Parameters

Fuel Ratio

Fuel ratio is the portion of the base heating demand supplied by coal and dRDF. Early tests have shown that 100 percent dRDF can be burned in WPAFB boilers with minor adjustments at low capacity, but without some coal there is a tendency to clog the fuel bunkers that feed the boilers (17). This option is therefore considered infeasible. Outside of short periods of specialized testing, the two fuels have been mixed 1:1 volumetrically for routine burning (38:14). Thus far only one boiler out of ten has used dRDF at any one time. The four-silo storage and fuel handling system presently could provide coal:dRDF mixtures by volume of 1:0, 1:1, 1:2, 1:3, 3:1, 2:1, 0:1. The last ratio has already been excluded, and ratios with more than two parts dRDF to one part coal are unlikely on a routine basis because the refuse fuel has a short storage life, even in a covered silo (27). To avoid dRDF clumping into large masses and the ensuing work of cleaning a plugged silo, only one silo has been used for dRDF. the dRDF is usually burned within a week, emptying the silo before the next delivery of fresh dRDF.

The contribution of each fuel towards total heat production when a mixture is burned is not simply the volume or weight proportions. The energy content and density of coal and dRDF are different. Using mid-values from Appendix B for heat content and density, the actual contribution of each fuel percentage-wise for several burning mixtures by volume was calculated for Table 6. Though it is possible that improved processing and experience in handling dRDF will allow an increased percentage of dRDF in the fuel mixture burned at this base, more than two parts dRDF to one part coal is considered unlikely.

TABLE 6

HEAT CONTRIBUTION OF COAL:dRDF VOLUMETRIC MIXTURES

	1:0	1:2	1:1	2:1	3:1
Coal	100%	58%	73%	85%	89%
dRDF	0%	42%	27%	15%	11%

<u>The Energy Content</u>

The energy content of coal and dRDF is needed in the model to convert the MBTU heating demand into the number of tons of each fuel required. The contracts for both fuels specify certain standards that each shipment must meet, but there is marked variation in the fuel characteristics from one shipment to another, especially in the case of dRDF. Appendix C shows some recent results of coal and dRDF laboratory tests for deliveries to WPAFB. Most runs of the model will use 13,750 BTU/lb (27.5 MBTU/ton) for coal and 6750 BTU/lb (13.5 MBTU/ton) for dRDF as representative values. Because fuel ratio (previous section) also depends on heat content, a change in heat content for either fuel will require new percentages be calculated for the heat contribution of each volume fuel mixture (as in Table 6).

The heating value of dRDF can vary greatly by processing method, geographical location, weather, season, and other factors (48:D-71). The present contract with Teledyne specifies a minimum heat content of 6500 BTU/lb for dRDF delivered to WPAFB and, as seen in Appendix C, it changes more drastically over time than does the heat content of coal. On the average, the heating value of municipal trash (the feedstock for dRDF) has been rising and is expected to continue that trend as more goods are packaged (43:8). One especially important factor in dRDF heating value is its ratio of paper and wood to other components, since those two items themselves have high heating values.

Base Price of Coal

The base price used in the cost model is from the 1980 coal contract, which is the last full year for which cost accounting records are available. The average price for the two suppliers was $38.00 (the contracts' estimate for the amount to be supplied was 52,500 tons for each company) (87).

Base Price of dRDF

The three-year period contract specified an FOB plant price of $27.00 per ton (70:p.2-1). Since this fuel is just a byproduct of Maryland's Environmental Services solid waste disposal operation, its price was set to half the mine price of high quality coal in 1979. This is somewhat unlike typical manufacturing, where the price for an item is initially derived from its production cost. The Teledyne plant started pelletizing RDF under U.S. EPA contract, and could stop with little impact on its primary role of shredding garbage to reduce the volume being landfilled (23). Several plants attempting to produce and sell RDF on a commercial basis have not met with success (67:26). Most operations are tied in with urban waste disposal, and installing expensive equipment to produce a salable fuel is a lower priority than the waste disposal. Difficulties with RDF processing equipment has raised the production cost to where landfilling is still the cheaper option for refuse disposal in many areas. As yet there is no market demand for RDF, and some test production runs could not even be given away by the producer (67:29).

Base Transportation Rate

The current necessity to transport dRDF by truck results in a per MBTU cost for dRDF of more than triple that of coal (Table 2). For that reason, long-distance truck transport costs for dRDF lead to an almost automatic decision to burn coal only when economy is a major concern. If dRDF were produced within twenty-five miles of the heating plants (70), however, the most probable mode of transportation would be by truck. It is assumed that dRDF will be trucked to WPAFB only for distances of twenty-five miles or less. For all other shipping distances, rail transportation is used in the cost model.

The railroad rates have been set by the Interstate Commerce Commission (ICC) and state public service commissions. The published interstate tariffs control much of the cost of shipping commodities such as coal (60), but as the industry is deregulated individual companies will be setting their own rates (65:39).

Early rail shipments of dRDF caused breakdown of the fuel pellets from jostling and moisture absorption (69:1-2). To ship dRDF over long distances satisfactorily by rail, covered cars and avoidance of enroute delays appear to be necessities. This special handling is reflected by a slight increase in the rail transportation rate for dRDF as compared to coal.

The ton-mile railroad shipping rate for both fuels used in this model is an effective rate, which includes the surcharges now being levied on rail shipments. This effective rate is obtained by dividing the distance shipped into the sum of the basic rate and surcharge.

Transportation Distance

The transportation distance is merely how far the fuel is shipped. The mileage times the effective rate provides the total transportation cost for each fuel. A more accurate method for calculating shipping charges is used in the Coal Electric Utilities Model (CEUM), where the total charge is the sum of a fixed charge and a per-mile charge for each route (20:3-238). The tables of charges for different regions and routings used in that model (developed under contract to the Department of Energy) were considered much too detailed for this project, so the simplified version described previously was used for the heating plant cost model.

Base Operations and Maintenance Expense

The O&M expense is made up of direct production labor, repair labor and materials, project and services contracts, shop overhead, and production supplies excluding solid fuel. Some items increase with the heating plant's output, while others are relatively stable despite changing output. Labor showed a very small change with output during three fiscal years (18), and so was considered constant. Many items such as boiler repair, electricity, ash disposal, make-up water and chemicals, fuel handling, and maintenance supplies varied with the plant output. The present Civil Engineering cost accounting system, however, lumps the variable items under several different headings making it difficult to trace the change in specific expenses for a change in plant output. Using records from another similar heating plant with more specific cost account divisions, estimates were made for the fixed and variable portions of O&M expense at WPAFB. The description and calculations used for deriving per ton and constant components of O&M costs are contained in Appendix H.

Fuel Price Inflation

The inflation in fuel prices is very difficult to estimate. One author generally put it this way: "No exact or standard technique makes allowance for future inflation, nor would one be valid since inflation rates cannot be predicted with certainty [52:94]." However, many of the factors that affect prices can be identified to gain some understanding of how particular prices are likely to change.

Figure 5 lists major items affecting the price of coal, and provides a good background for attempts at estimating future coal prices. Listed in Appendix I are some historic price changes for coal, as well as some estimates of future prices from various sources. In general, coal prices have followed oil prices (though rises have not been as sudden and sharp as for oil), and will probably continue to do so.

The current contracts with Pittston and Tricentennial coal companies call for a minimum heating value of 14,200 BTU/lb.[2] This high quality bituminous coal is washed, oil-treated to prevent freezing, and has a low sulfur content (0.6 percent). These characteristics make it likely that as the average heating value of coal mined in this country decreases (79:109), this "Cadillac coal" (68) will increase in price faster than the average coal prices unless air quality standards are markedly relaxed.

There is no extended price history for dRDF. Similarly, no estimates for the future price or availability of dRDF exist either (83). The price of dRDF will probably be constrained to a percentage of prevailing coal prices, based on heating value (64). While technological advances in solid waste processing will make that young

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[2]Actual payments under the present coal contracts are tied to the heating content of the coal received, as confirmed by laboratory analysis. More or less than the stated price may be paid according to where the actual heating value falls (6).

FUTURE COAL PRICES

Supply Forces

1. Size, accessibility and quality of coal reserves

2. Resolution of social and ecological problems with coal development

3. Development of transportation facilities, especially from western reserves

4. Availability of labor and capital for coal development

Demand Forces

1. Future prices of substitute energy sources

2. Growth rate in domestic coal-using industries

3. Pollution control choices faced by industry

4. Growth in foreign demand for U.S. coal

Fig. 5. Factors Affecting Future Coal Prices (Adapted from 30:51)

industry more efficient, dRDF prices will almost certainly follow coal prices, because it is a close substitute for coal. It is possible that dRDF could be obtained at substantially lower prices since it is a byproduct of solid waste disposal operations, but it is more likely that anyone producing it for sale will try to get a price consistent with prevailing prices for other fuels.

Transportation Inflation

The effect of deregulation on the transportation industry will have a strong impact on shipping costs, especially for railroads. The 1980 Decontrol Act allows railroads to raise rates 6 percent above inflation until 1985, and up to 4 percent above inflation after that, as long as the combined totals don't exceed 18 percent annually (61). (The ICC maintains some control by choosing how inflation is to be measured.) This law was seen as a remedy for the overregulation which has handicapped railroads in the recent past. It is expected to improve their ability to meet future transport demands, especially for moving coal (28).

Railroads are almost certain to use their new rate setting freedom. Even before the law went into effect, one line gained ICC approval for large increases in coal freight rates charged to San Antonio--after the city dutifully converted its electric utility to coal[3] and became a captive market for low-sulfur Wyoming coal (65:40). Sharp rate increases like that would have been prohibited in the past. Such increases are justified, however, because of the expense to refurbish road beds under the heavy traffic of steady coal shipments. The rate of return has also been quite low for railroads, averaging 1.74 percent over the last five years as compared to 15.9 percent for the trucking industry (65:39), making it difficult to fund repairs and capital improvements.

Another factor acting to raise rail freight rates is the increasing portion of operating expenses taken up by fuel and power. Ten years ago these expenses comprised only 3 percent of total operating expenses, but now they take up almost 12 percent (86). If energy prices continue to rise faster than other prices, that percentage will increase and drive up freight rates faster. Considering all these factors, the change in coal freight charges over the last decade (Appendix J) is assumed to continue, and so is used as the basis for the transportation inflation rate employed in the cost model.

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[3]Following the intent of the Carter Administration coal conversion program as contained in the 1978 Industrial Fuels Act.

Functional Relationships

The activities that connect the elements of the cost model are shown in Figure 6, for one year's accumulation of operating costs.

Sample from Weather Distribution

The weather sample is a random sample from a Normal distribution with mean 5497 and standard deviation 380.4, which represents the yearly temperature (in HDDs) for which the heating plants provide heating.

Convert Annual Heating Degree Days to MBTUs

The conversion of HDDs to MBTUs utilizes the general heat flow equation $Q = U \cdot A(\Delta t)$; where "Q" is the energy required in MBTUs, "U" is the resistance to heat flow of the space boundary, "A" is the area of the space being heated for a standard ceiling, and "Δt" is the difference in temperature across the boundary. This equation usually refers to heat flow per hour out of a space, but for modeling purposes both sides were multiplied by the hours in a year so that the Q is the yearly heat required and Δt is the total yearly temperature difference. The units for those quantities are MBTUs and HDDs, respectively.

The Q figure represents the output of the heating plants. To find the input Q which represents the energy content of the fuel going into the boilers, a thermal

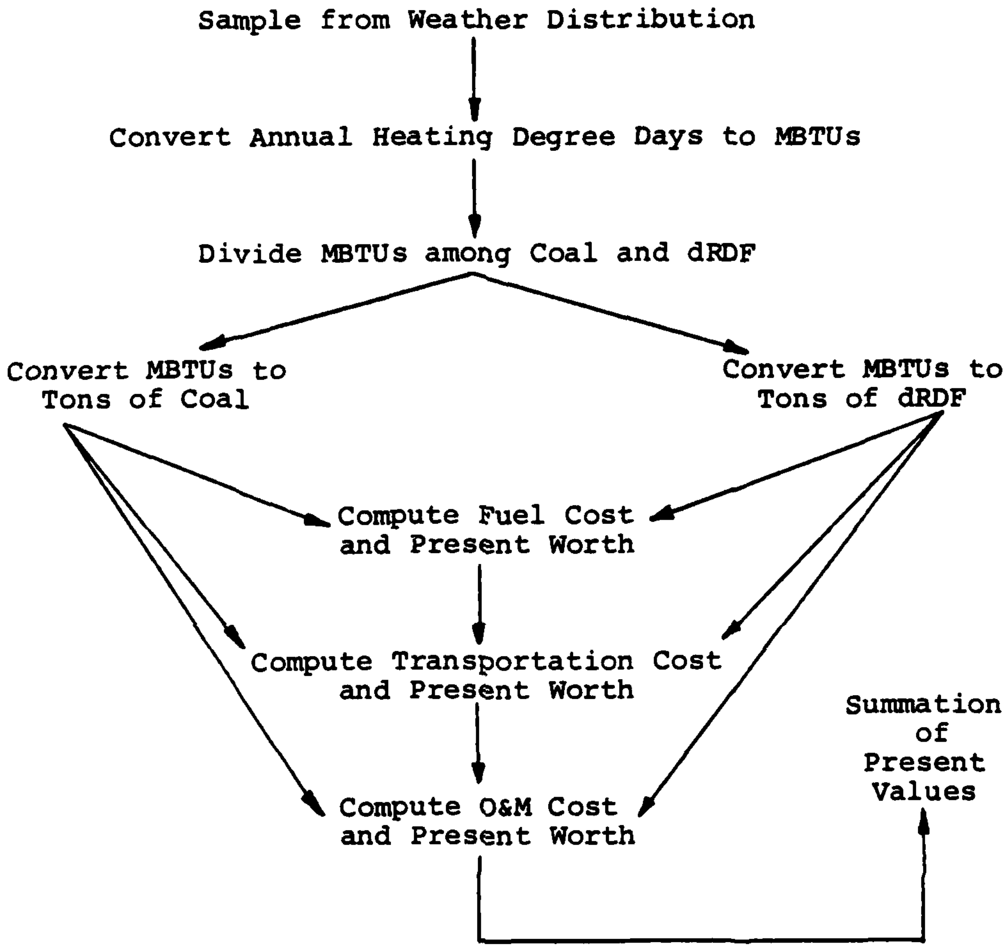

Fig. 6. Activity Diagram of Heating Plant Cost Model

efficiency factor must be applied. Appendix K contains excerpts from WPAFB heating plant operating logs, and lists the input and output Q's for a recent period. The ratio of output to input is the boiler efficiency, which for the WPAFB heating plants is 0.805. With this information, the equation for input MBTUs needed to meet a year's heating degree day demand is:

$$\text{Input } Q = U \cdot A \cdot (HDD)/0.805$$

The product U·A was calculated indirectly by providing figures for Q and HDD from historical records, and was assumed to remain constant for the twenty years over which the model operates. (This simplifying assumption was used because as the heating efficiency of base buildings is improved, the total floor space being heated is increasing. Most new buildings are connected to the central heating plant lines. The net result is a negligible change in the value for U·A.) The model uses this constant UA factor to calculate the input Q required for each future year's HDD demand. The development of this and other mathematical relationships used in the model is contained in Appendix L.

Divide MBTUs among Coal and dRDF

The total number of input MBTUs required to meet the weather-caused heating demand is divided between the two fuels. The percentage of that total provided by one fuel can range from zero to one hundred; the remaining portion being contributed by the other fuel. (Heating contribution percentages for various fuel mixtures were computed in Table 6.)

Convert MBTUs to Tons of Fuel

Converting the input MBTUs to tons of coal and/or dRDF is accomplished by dividing fuel heat content per ton into the number of MBTUs of heating demand each fuel is assigned.

Compute Fuel Cost

The fuel cost is computed by adding the products of each fuel's base price, quantity in tons, and present value factor.

Compute Transportation Cost

Calculating the transportation cost requires the multiplication of fuel tonnage, effective rail rate, distance shipped, and present value factor. The dRDF portion of the calculation includes an additional factor of 1.17 to account for special handling expenses. The sum of present value transportation costs for the two fuels is the total present value transportation cost for one particular year.

Compute O&M Cost

Computing the operation & maintenance expense entails multiplying fuel tonnage with a direct production figure to simulate cost variability with output, and adding that to an amount representing fixed O&M expenses. A present value factor is applied to each O&M expense, and the total present value O&M cost for the year is the sum of the individual coal and dRDF O&M expenses.

Present Value Factor

Both inflation and discount rates are included in the model by multiplying each annual cost computation (fuel, transportation, operation & maintenance) by the present value factor:

$$(1+I)^n \;/\; (1+r+I)^n$$

where "I" is the yearly inflation, "r" is the discount rate, and "n" is the future year number (52:109). In this model allowance has been made for using different inflation rates for the price of coal, the price of dRDF, freight rates, coal O&M costs, and dRDF O&M costs. The resulting flexibility increases the ability of the model user to analyze the effects of different financial assumptions on the cost model's output.

Summation of Present Values

The three values for fuel, transportation, and operation & maintenance are added to arrive at a single present value operating expense for a particular year.

Computerization

The heating plant cost model was programmed for the computer using the Q-Gert simulation language with FORTRAN subroutines. Though Q-Gert is best utilized in queueing simulations, its library of probability distributions, time incrementing method, and ready-made storage arrays make it useful for other type models such as the one presented here. The flowchart, program description, computer variables, statement coding, and a sample output are included in Appendix M. The name given to this computer model is HTGPLNT.

Verification and Validation

Verification of the cost model consisted largely of debugging the computer program. After the program began to run (apparently) properly, a manual calculation of the costs for several years using the generated weather sample was compared with the computer output. This ensured that HTGPLNT's logic and calculations were operating as intended. That comparison revealed a problem with the model's time incrementing during the later states of model development;

but was corrected before the final experiment runs were made.

The only validation offered for this model is that its operating expense components are similar in magnitude to those of heating plants in general. The dispersal of some of Wright-Patterson's heating operating expenses to other cost accounts (such as utility and transportation charges) makes precise validation of the model with existing financial records extremely difficult. The model output is based on a more complete accounting of heating plant expenses than is presently the case with the BEAMS heating plant cost account. The difference is significant enough to suggest caution in trying to validate the model output with the present 2750th Civil Engineering Squadron cost account records.

CHAPTER V

THE EXPERIMENTS

Purpose of Experiments

The purpose of conducting simulation experiments with the model is to study the heating plants' operating costs for different fuel combinations. A specific set of future conditions may point to one combination as the most economical. But because of the uncertainty in the future environment (and in the validity of model parameters and relationships), several experiments were conducted to see how the model's output was affected by changes in specific conditions. An additional benefit to be gained from experimentation is better understanding of the system's operating cost behavior.

How the Computer Runs Were Made

The simulation model was designed to accumulate cost data for twenty time periods, corresponding to years of operating expenses. A single run of the model consisted of eleven repetitions (of twenty time periods) using a different random number seed for each repetition. A data point was the average value of the output variable of interest (fuel cost, transportation cost, operation & maintenance cost) for the eleven repetitions. Eleven was chosen for the number of replications to obtain a 90 percent confidence that the calculated mean ($\bar{x}$) for the runs was within one-half standard deviation of the actual mean (μ).[1]

Comparative Analysis

The examination of changes from standard cases (44:203), was used to analyze the output from HTGPLNT. The items compared were the average heating plant operating costs from a standard case to one or more alternate cases. The items changed from one case to the next can be generally classified under the four categories suggested by Watson, as shown in Figure 7.

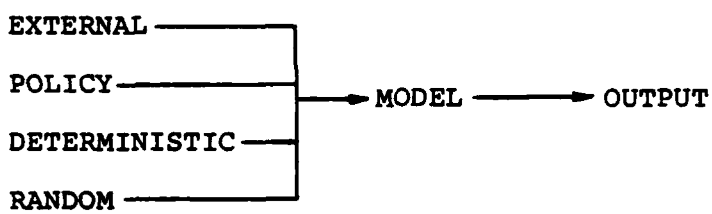

Fig. 7. Variables in Simulation Models

The external variable for HTGPLNT is the weather sample, which is considered independent and beyond control. Policy variables, which can be changed by managerial action,

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[1]Without knowing the feasible range of outputs or the true standard deviation, the sample size required for this probability is (66:188):

$$n = (\sigma Z_{\alpha/2})^2/(\sigma/2)^2 = (2)^2(1.645)^2 = 10.8$$

(Assuming each output variable is normally distributed.)

include the fuel ratio, the heating content of the fuels, and the shipping distance. The future changes in fuel, transportation, and operation & maintenance expenses are uncertain enough to be classified as "random," but for HTGPLNT they are deterministic. These constant rates of inflation are combined with fixed baseline costs to arrive at the future costs for the items.

A total of twenty-eight different runs were accomplished with HTGPLNT, all of which are listed in Appendix N. (The average computer cost per run was ninety-eight cents.) Various combinations of those runs were chosen to conduct experiments. The runs and combinations were used to simulate specific conditions, and thus allow a comparison of present value (PV) average total operating cost for different conditions. In the following sections the scenario, baseline conditions, and output comparison for each experiment are detailed.

Fuel Mixture Experiment

In the first experiment the ratio of coal to dRDF "burned" in the boilers was varied to determine the least expensive fuel mixture. The four coal:dRDF mixtures considered were 1:0, 2:1, 1:1, and 1:2. Initial fuel prices, transportation rate and distances, operation & maintenance expenses, and heating values were the same in each of the four runs. The inflation rates and discount rate were zero, so the output is in 1980 dollars. Figure 8 illustrates the

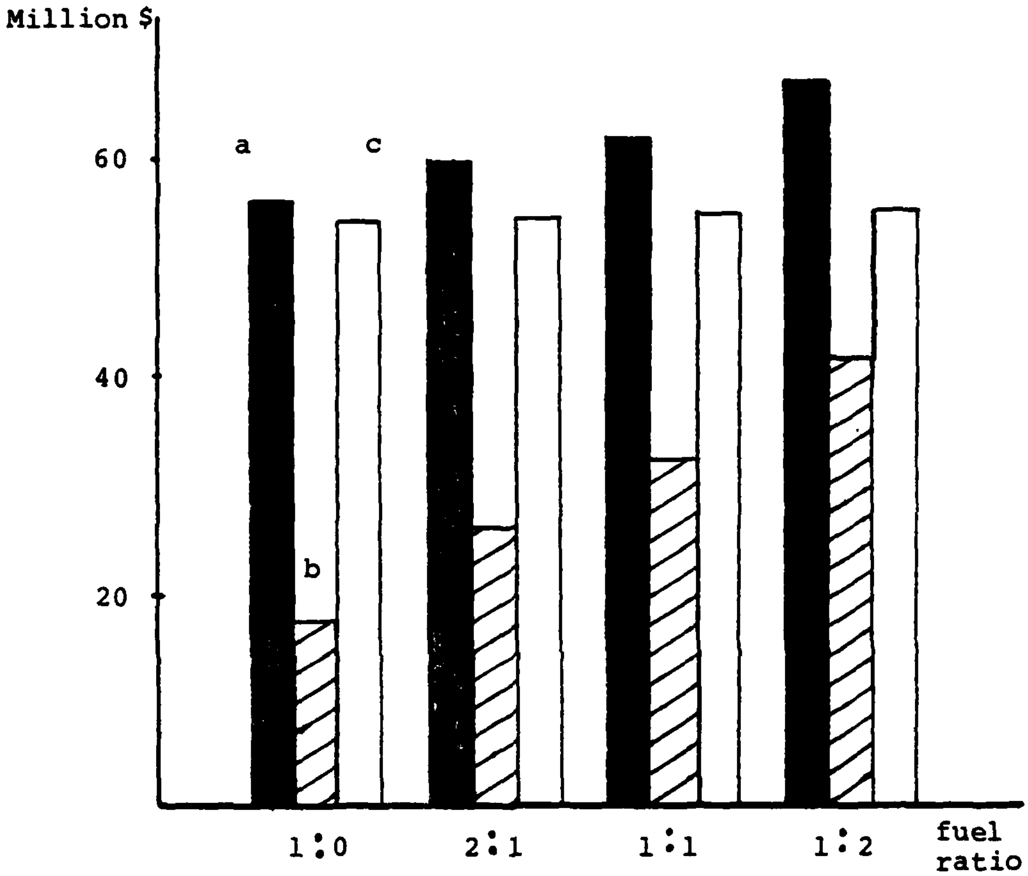

Fig. 8. Cost Components for Various Fuel Mixtures (Inflation & Discount Rates Zero)

a. Fuel.

b. Transportation.

c. Operation & maintenance.

changes in operating cost components as the fuel mixture is varied. These results indicate that the 1:0 fuel mixture (coal) incurs a lower operating cost than the other mixtures tested under the assumptions made in formulating this cost model.

The first experiment was extended to see if inflation and discount rates for all the cost elements would alter the fuel mixture choice. Eight more computer runs were made using likely inflation rates for fuel, transportation, and operation & maintenance (Appendix I). In addition, runs five through eight used a discount rate of 7 percent as called for in the National Bureau of Standards Life Cycle Cost Manual (55:iii), while runs nine through twelve used the 10 percent discount rate required for USAF economic analyses (77:2-1). Table 7 summarizes the total costs from all twelve runs. The increasing discount rate decreases the dollar amount as would be expected, while maintaining the same progression of higher costs for greater dRDF content in the fuel mixture as demonstrated by the first four runs.

Operation & Maintenance Cost Experiment

Among the three starting condition costs, the accuracy of operation & maintenance is the most doubtful. The reason for this is that the present cost accounting system in base civil engineering does not distinguish

TABLE 7

FUEL MIXTURE EXPERIMENT RESULTS

Coal:dRDF Fuel Mixture	Twenty Year Operating Cost (Million $) 0% Discount	7% Discount	10% Discount
1:0	126.8	74.4	62.0
2:1	139.8	82.1	68.4
1:1	150.3	88.3	73.6
1:2	163.4	95.9	80.0

between many of the resources used for a particular activity. That system is aligned more for Air Force budget authorizations than it is for monitoring production expenses. Some of the direct expenses for operating the heating plants are excluded from its cost account (electricity), or paid for out of other organizations' budgets (freight charges for fuel).

There is a need for tracking operating expenses accurately because without such records it becomes very difficult to choose wisely among alternatives for resource utilization. That need is more pressing when a significant change is contemplated, such as the burning of refuse-derived fuel at WPAFB. Whether it be for validating engineering estimates, operating the plant economically, budgeting for future expenditures, or evaluating fuel alternatives, accurate cost data for distinct areas of production expense are needed. The sub-account headings used for the central heating system at the Dayton Veteran's Administration Medical Center (Appendix E) offer one example of such expense areas. Identifying those expenses is the first step in managing them efficiently.

Lacking the appropriate detail in the WPAFB heating plant cost accounts, an estimate was made for several of the expenses imbedded in the BEAMS cost accounts (Appendix H). To assess the effect on HTGPLNT's output from a possible error in the initial value for operation & maintenance expense, two computer runs with adjusted O&M baseline costs were compared with a standard case (run eleven). Run thirteen was made with a 10 percent decrease in the fixed portion of O&M expense, while run fourteen incorporated a 10 percent decrease in the variable portion of O&M expense. All other parameters for the three runs were identical.

The results of this experiment (Table 8) showed the greatest impact on total operating cost by the change in fixed O&M cost. A 10 percent reduction in fixed O&M brought a 3.4 percent decrease in total operating cost for HTGPLNT. The same percentage decrease in the initial value of variable O&M expense only changed total cost by 0.02 percent.

Selected Inflation Experiment

The freight, coal price, and dRDF operation & maintenance inflation rates were changed sequentially in this

TABLE 8

OPERATION & MAINTENANCE COST EXPERIMENT RESULTS

	Twenty Year Operating Cost ($ Million PV)	% Change	O&M% of Total	Run Number
Standard Case	73.554	--	36.5	11
Decrease in Fixed O&M	71.077	-3.36	34.3	12
Decreased Variable O&M	73.541	-0.017	36.5	13

experiment, and the outputs compared to those of the standard run (number eleven). The standard case freight inflation of 9.4 percent was reduced by 10 percent (to 8.5 percent) in run fifteen to mimic the situation where rail transportation rate increases follow general price rises more closely, rather than outstripping them significantly. Annual coal price inflation was increased by 10 percent in run sixteen to see how faster hikes in coal prices would affect the output from HTGPLNT. Faster price rises would be likely if the demand for coal increased markedly (as might be the case if liquid or gaseous fuel production from coal develops into a large industry).

There has been concern over boiler corrosion from dRDF burning. One boiler tube sample from WPAFB was sent to the National Bureau of Standards (NBS) for corrosion analysis, but insufficient data on the conditions it was subject to inside the boiler made an accurate evaluation of corrosion rates impossible (36). Battelle Laboratories have conducted experiments with bulk refuse burning, and found that the increased corrosion from chlorine could be controlled by co-firing the refuse with high sulfur coal (82:65). Limiting boiler flame temperature also mitigated the corrosion (47:594). More frequent repair of boiler components, as might result from long-term dRDF use, was modeled by increasing the O&M inflation rate for that fuel 10 percent (run seventeen).

The results in Table 9 show the same direction of change from inflation to operating cost, but at roughly an order of magnitude less. The O&M cost change was much smaller than the other two, largely because only a small portion of the total O&M cost (7 percent) was allocated as a variable (per ton of fuel burned) expense.

TABLE 9

SELECTED INFLATION EXPERIMENT RESULTS

	Twenty Year Operating Cost ($ Million PV)	% Change	Run Number
Standard Case	73.554	--	11
Decreased RR Freight Inflation	73.479	-0.10	15
Increased Coal Price Inflation	73.638	+0.11	16
Increased dRDF O&M Inflation	73.558	+0.005	17

Shipping Distance Experiment

Coal prices in any particular area of the country are quite dependent on transportation costs (30:80). As already demonstrated (Table 2), this applies as well to another solid fuel like dRDF. In this experiment the distance is changed in the model to simulate state (run eighteen) and local (run nineteen) sources of dRDF.[2] While neither area has a dRDF production plant presently, resource recovery facilities capable of producing RDF are in the advanced planning stages for Toledo, Cincinnati, and Cleveland (62:10). While Dayton seems to have opted for mass burning of refuse for area steam production (14; 26), difficulties with the present incinerators or changes in public office-holders could bring a change in direction for local solid waste disposal. It is even conceivable that WPAFB could build or participate in the building of a dRDF production plant (10; 68).[3]

The results from those runs are displayed in Table 10, where the standard case is the same as used in the previous two experiments. The decreases in shipping distance for dRDF bring the total operating cost for the two test

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[2]The potential state source used in the model was Toledo, located about 141 miles from WPAFB. The local source was assumed to be located within ten miles of the base, but twenty-two was used in the computer run to imitate the more expensive rates for truck transportation.

[3]It should be noted, however, that such involvement with a refuse processing operation poses some risks to the base.

TABLE 10

SHIPPING DISTANCE EXPERIMENT RESULTS

	Twenty Year Operating Cost ($ Million PV)	% Change	Transport % of Total	Run Number
Standard Case	73.554	--	21.9	11
Ohio Source	67.282	- 8.5	14.6	18
Local Source	64.172	-12.8	10.4	19
Coal Only	62.006	-15.7	13.6	9

cases considerably closer to the coal-only operating cost. Though a local source of dRDF does not make a 1:1 coal-dRDF mixture less expensive to use than coal alone, it is highly likely that Wright-Patterson's refuse disposal costs would be decreased enough to offset that difference. As recommended in previous studies, the installation could include a stipulation in the RDF purchase contract that the production facility accept the installation's refuse at little or no charge to the government (63:16).[4]

Energy Content Experiment

The present energy content specification for dRDF delivered to WPAFB is a minimum of 6500 BTU/lb. The actual heating values for various shipments during one recent

[4] A thesis written by Hatch and Mansfield put the total cost of refuse collection and disposal at fifty to seventy-five dollars per ton for Wright-Patterson during 1979.

period ranged from 5751 to 9787, with an average of 8137 BTU/lb (Appendix C). This suggests that a higher energy content specification than the present one may be feasible. (Though the use of more process energy in dRDF production than is available from burning the fuel would not be an economical choice. Increased processing to raise the dRDF's heating value would certainly increase its cost to the consumer.) It also means that the actual heating contribution of dRDF is higher than would be assumed with the contract specification.[5]

Testing the effect of different dRDF energy contents on operating cost was done by comparing outputs from these three runs. The standard case uses 6750 BTU/lb, while the other two use 7425 (10 percent higher) and 8100 (20 percent higher). All other parameters were identical for the three runs. Table 11 shows the results, and indicates that a 5 percent change in energy content will cause roughly a 1 percent change in operating cost.

Proper Fuel Price Experiment

The unexpected drop in coal prices during 1980 shown in Table 12 made the dRDF price disproportionately high in comparison. To observe the effect on total operating cost with the original price structure, the

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[5]The WPAFB heating plant employees presently use 6500 BTU/lb for dRDF when completing the boiler operating logs.

TABLE 11

ENERGY CONTENT EXPERIMENT RESULTS

	Twenty Year Operating Cost ($ Million PV)	% Change	Fuel % of Total	Run Number
Standard Case 6750 BTU/lb	73.554	00	41.6	11
7425 BTU/lb	71.945	-2.2	41.3	20
8100 BTU/lb	70.837	-3.7	40.9	21

TABLE 12

PURCHASE PRICES OF SOLID FUELS USED AT WPAFB (70:p.2-1; 11; 87)

	Apr 79-Mar 80	Apr 80-Mar 81	Apr 81-Mar 82
Coal ($/ton)[a]	49.59	38.00	40.75
dRDF ($/ton)	27.00	27.00	27.00

[a]Average FOB mine price for equal shipments from two suppliers.

standard case was compared with one where the base price of dRDF was decreased to half of the baseline coal price.

Additional runs were made with the new base price, and increased dRDF O&M inflation, for three shipping distances. The coal-only operating cost was also compared with those three runs. This comparison was to help discern whether the combination of a "proper" price but a higher O&M inflation rate for dRDF, still caused the three runs' operating costs to exceed the coal-only operating cost for several dRDF shipping distances. The dollar amounts generated in those computer simulation runs are listed in Table 13. The operation & maintenance inflation change had a very small effect on operating costs. The 30 percent drop in dRDF baseline price and the shorter shipping distances combined to undercut the coal-only operating cost for the local dRDF source case.

TABLE 13

PROPER FUEL PRICE EXPERIMENT RESULTS

	Twenty Year Operating Cost ($ Million PV)	Old % Change	New % Change	Run Number
Standard Case	73.554	--	--	11
New Standard (dRDF price)	70.391	- 4.3	--	22
Increased dRDF O&M Inflation	70.395	- 4.3	+0.006	23
Ohio Source, High O&M Inflation	64.123	-12.8	-8.9	24
Local Source, High O&M Inflation	61.013	-17.1	-13.3	25
Coal Only	62.006	-15.7	-11.9	9

Multiple Inflation Experiment

One of the methods that has gained some popularity for estimating future energy demand, supply, and price is to develop a low, most likely, and high estimate for the item of interest (56; 80). This technique helps make the uncertainty in such things as future energy prices somewhat more manageable. The researcher can choose a sequence of events, and based on the assumption that things occur that way, project their impact on the item of interest. Several different sets of circumstances could be investigated, and a more probable range of values for the item could be proposed.

The final experiment in this thesis looks at the effect on operating cost of three different estimates for inflation. For this last set of computer runs, it was assumed that dRDF would cost half as much per ton as coal, and would be available from an Ohio source. Each run used a single inflation rate (from Appendix I), and from the results listed in Table 14 it can be seen that the range of inflation rates had a surprisingly small effect on the twenty-year present value operating cost for this model. The reason why is that the inflation and discount rates cancel one another; so that it is only their difference that affects the output figures generated by the cost model.

TABLE 14

MULTIPLE INFLATION EXPERIMENT RESULTS

	Twenty Year Operating Cost ($ Million PV)	Run Number
Inflation 4.8%	63.038	26
Inflation 7.7%	64.032	27
Inflation 10.5%	64.967	28

Sensitivity Ratings

Throughout the previous experiments, parameter values were varied to determine their effect on the model's output. One way to measure the strength of each parameter's effect on HTGPLNT's output is to use the efficiency concept of output divided by input. Table 15 contains the results from calculating the "efficiency" for several of the factors tested in the different experiments. The numbers listed there have been named Sensitivity Ratios (SR) and are obtained as follows:

$$SR = \frac{\%\ \text{Change in Output}}{\%\ \text{Change in Factor Tested}}$$

If the output changes in the same direction as the factor was changed, the SR is preceded by a plus sign; otherwise by a minus sign.

The usefulness of these ratios is in being able to choose the most efficient or available factor to vary

TABLE 15

HTGPLNT SENSITIVITY RATIOS

Fixed Operation & Maintenance	+ 0.3367
Heating Content, dRDF (ave.)	- 0.2017
New dRDF Price	+ 0.1451
Shipping Distance, dRDF	+ 0.1354
General Inflation, 7.7 to 10.5	+ 0.0402
General Inflation, 4.8 to 7.7	+ 0.0261
Coal Price Inflation	+ 0.0114
Railroad Freight Inflation	+ 0.0102
Variable Operation & Maintenance	+ 0.0017
O&M Inflation, dRDF	+ 0.0005

(within existing constraints) to make a desired change in the output. The numbers in Table 15 apply to the model formulated in this thesis, but may indicate the relationships between those factors and the real system's "output." The generalizability of such ratios to a real system depends on how accurately a model portrays the actual system.

CHAPTER VI

CONCLUSION

Overview and Limitations

The intent behind this thesis was to analyze the effect of dRDF use on heating plant operating costs at Wright-Patterson AFB. To pursue that goal, an economic model of the present heating system was developed. Different environmental conditions and managerial decisions were simulated by changing model parameters. The output from the model for the various situations was compared to see which factors had the greatest effect on operating costs.

There is adequate reason to question the accuracy of the data generated by the model. Though care was taken in developing the parameters and relationships, difficulty in validating the model leaves some doubt as to how well it mirrors the cost performance of the actual system. Part of this difficulty was cuased by the orientation of the present USAF Civil Engineering Cost Accounting System. Another part was due to the lack of technical information concerning long-term dRDF use--which is a prerequisite for an accurate study of this type. One of the foremost experts in the field expressed the second point this way:

"Prior to the economic analysis, the military planner must have accurate and precise information regarding the technology involved to produce and/or use dRDF [42:11]." Some of that information is being gathered now. As more becomes available, researchers will be able to make better operating cost projections, even with the uncertainty in future prices. Such projections are useful because they may help avoid making a choice which is likely to cost much more over the long run than its short-term analysis would indicate.

The model used in this thesis was developed specifically for Wright-Patterson AFB. As such, the results obtained from experimentation with it cannot be assumed to apply to heating systems at other installations. The basic structure of the model may be transferable, but many of the parameters and relationships would have to be adjusted for each location.

Original Hypothesis

The introductory chapter in this thesis proposed the hypothesis that coal could be less expensive to use in the Wright-Patterson AFB heating plants over the next twenty years than a mixture of coal and dRDF. Projecting over that period with the present fuel price structure and likely rates of inflation, a cost model of the heating system indicated this to be true.

Conclusions

Based on the assumptions used in developing the heating plant cost model, and the results from conducting experiments with it, several conclusions were reached. It must be remembered, however, that these assertions were derived from the model, and so must be applied with caution (if at all) to the real system.

1. An increasing percentage of dRDF in the fuel mixture causes higher heating plant operating costs for the present price structure and fuel sources at WPAFB.

2. Discount rate does not affect the choice of fuel alternatives when the comparison uses twenty-year operating costs for each fuel mixture.

3. The effect of fixed and variable operation & maintenance expenses on model output depends on how much of the total O&M expense is allocated to each.

4. The coal-only boiler fuel alternative remains the most economical until the price of dRDF is about half the price of the present grade of coal being used at WPAFB, and a local source of dRDF is available. The combination of price and transportation cost for dRDF must be less than that for coal (on a heating content basis) before the two fuels can indicate the same total operating cost in the model.

5. The model is most sensitive to changes in baseline operation & maintenance cost, fuel heating content,

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AN ECONOMIC MODEL OF FUTURE COAL/DENSIFIED REFUSE-DERIVED FUEL --ETC(U)
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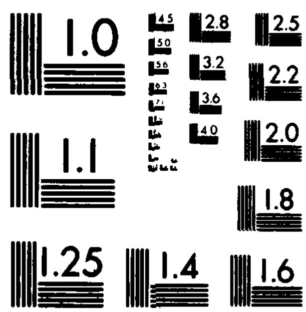

MICROCOPY RESOLUTION TEST CHART

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fuel baseline cost, and fuel shipping distance. The effect of inflation on the model's output depends on the size of the difference between annual inflation rate and discount rate.

Recommendations

1. The present USAF cost accounting procedures for heating plants should be modified to reflect the full cost of heat production. The present method, where other functional areas or even other organizations pay some of those expenses, makes economic comparison of operating alternatives very difficult. Tracking those costs will probably entail changes in expense reporting and recording, which may require the installation of electric and water meters on the heating plants.

2. Consideration should be given to including an adjustment clause in future refuse-derived fuel contracts so that the price paid for dRDF does not exceed a certain percentage of the prevailing market price for a specified grade of coal. Tighter enforcement of fuel specifications should also be achieved on those contracts.

3. The emphasis within the USAF for increased utilization of alternate fuels may not be the most economical path for meeting an installation's heating or power needs. If waste-derived fuels are to be used,

however, planners should concentrate on local sources for each facility to avoid large transportation costs.

4. Where local RDF production is not likely, DOD installations should conduct studies on the feasibility and economy of energy recovery from the high quality mixed paper available from their offices.

5. Future economic studies of military dRDF use should include the impact on installation waste disposal and related pollution control costs over the same period.

APPENDICES

APPENDIX A

GLOSSARY OF TERMS

Air Classification--the separation of mixed material by injection into a forced-air stream. Pieces are separated according to size, bulk, density, and aerodynamic drag (57:1).

Base Engineer Automated Management System (BEAMS)--a management information system that provides bookkeeping and data analysis services to the base civil engineering function.

British Thermal Unit (BTU)--The quantity of heat necessary to raise the temperature of one pound of water one degree Fahrenheit (25:468).

Clinkers--ash that fuses into a solid mass or sheet inside the boiler (38:16). They may interfere with ash removal, and can harm the metal grates which support the burning fuel.

Densified Refuse-Derived Fuel--a refuse-derived fuel which has been compressed or compacted to improve certain handling and burning characteristics (57:2).

Discount Rate--the percentage rate used to transform future costs to their present-day worth. It allows cost comparison of alternatives that have different expenditure patterns over time (77:A-1).

Dump--an open land site where waste materials are burned, left to decompose, rust or remain. Because of the air and water pollution, unsightliness, and unsanitary conditions they create they have been declared illegal in all states (57:2).

Eddy Current Separation--a method of separting non-magnetic metals such as aluminum by temporarily "magnetizing" them with electrodynamic induction (57:2).

Electrostatic Precipitation--a process for removing particles from a solution by charging them electrostatically and then collecting them on a pipe or metal plate (57:2).

Energy Recovery--a form of resource recovery in which the organic portion of waste is converted to useful energy (57:2).

Ferrous--metals which are predominantly composed of iron, and are usually magnetic (57:2).

Fines--loose paper and plastic less than about one-half inch which accompanies a dRDF shipment (16:26). Fines may be caused by pellet breakdown during handling, or by material leak-through during production. Generally, they include any unpelletized material that comes with dRDF.

Fixed Cost--the cost of an activity that remains fairly constant throughout the range of production (32:35).

Fly Ash--small particles of ash and soot generated when coal, oil, or waste materials are burned (57:2).

Fossil Fuels--coal, oil, and natural gas, which are the remains of ancient plant and animal life (25:470).

Free On Board (FOB)--denotes a transaction where the seller makes a product available with an agreement on a given location at a given price. It is the responsibility of the buyer to arrange for the transportation and insurance of the product (79:105).

Froth Flotation--a process commonly used in the minerals industry, which takes advantage of the affinity some crushed materials have for air bubbles introduced from the bottom of a chemical tank. This method is used to recover sand-sized particles of glass (57:2).

Grate--a frame of metal bars for holding burning fuel in a furnace (73:576).

Heating Degree Days (HDDs)--the deviation of the mean daily temperature below 65°F. For example, a weather station recording a mean daily temperature of 50°F would report fifteen heating degree days for that date (78:99).

Leachate--liquid containing decomposed waste, bacteria, and other potentially harmful materials which drains from landfills (57:3).

Make-Up Water--the treated water added to the steam or high termparature hot water heating system to replace water lost due to leaks in the return lines.

Materials Recovery--the initial phase of a resource recovery system where recyclable and reusable materials are collected for sale (57:3).

MBTU--one million British Thermal Units.

Mixed Paper--waste paper of various kinds and quality, usually collected from stores, offices, and schools (57:3).

Municipal Solid Waste--the combined residential and commercial waste materials generated in a given municipal area (57:3).

Present Value (PV)--each year's expected cost multiplied by its discount factor, summed over the number of years in the period (77:A-1).

Refractory--the brick lined area of a furnace (73:1109).

Refuse-Derived Fuel--a solid fuel obtained from municipal solid waste as the result of processes that improve the physical, mechanical, or combustion characteristics of the original feedstock (57:3).

Resource Conservation and Recovery Act of 1976--the law that amends the Solid Waste Disposal Act of 1965, and expands on the Resource Recovery Act of 1970. It provides a program to regulate hazardous waste; to promote solid waste management programs through financial and technical assistance; and to conduct research, development, and demonstration programs to improve solid waste management, resource conservation, and recovery practices (57:3).

Rodding--repeated pushing of a stick or pipe (rod) through a clump of material, to loosen the mass and allow it to flow.

Screening--the separation of pulverized waste material by size using sieve-like devices (57:4).

Scrubber--a device for removing dust particles from an air stream by spraying with water or forcing the air stream through a series of liquid baths (57:4).

Shredder--a mechanical device which breaks up waste materials by tearing and impact action (57:4).

Slagging--the build-up of molten or fused ash on inner boiler surface, which reduces heat transfer and thus boiler efficiency (38:16; 41:74).

Solid Waste--discarded solid materials, including agricultural waste (animal manure, crop residues), mining waste (tailings), industrial waste (manufacturing residues), and municipal waste (57:4).

Stoker--a mechanical device for supplying coal or a similar solid fuel to a boiler (73:1293).

Sunk Cost--past expenditures related to a project. They are not relevant to decision makers since they reflect previous choices (77:A-2).

Urban Waste--the general category for the entire waste stream from an urban area (57:4).

Variable Cost--a cost that varies in some way with the level of production (32:35).

Volume Reduction--the processing of waste materials so they occupy less space. Three methods are mechanical (compaction, shredding), thermal (incineration, pyrolysis), and biological (composting) (57:4).

Waste Stream--a general term used to denote the waste material output of a facility, location, or area (57:4).

Water-Wall Furnace--a furnace constructed with walls of welded steel tubing through which water is circulated to absorb the heat of combustion. These furnaces are commonly used as incinerators. The hot water or steam produced may be put to a useful purpose, or simply carry the heat away to the environment (57:4).

Wet Pulping--a wet shredding process which seems to reduce the likelihood of explosion from dust (42:29).

APPENDIX B

COAL AND dRDF PHYSICAL CHARACTERISTICS (38:15)

TABLE 16

COAL AND dRDF PHYSICAL CHARACTERISTICS

	dRDF	Coal
Energy Content (BTU/lb)	6500-7000	13,500-14,000
Moisture Content	14%	5%
Ash Content	11%	7.5%
Sulfur Content	0.1%	0.7%
Bulk Density (lbs/cu ft)	35	45-50

APPENDIX C

LABORATORY ANALYSES FOR dRDF AND COAL USED AT WRIGHT-PATTERSON AFB OH

TABLE 17

DELIVERY ANALYSIS OF dRDF (69:p.4-4)

	Energy Content BTU/lb	Ash Content %	Moisture Content %	Bulk Density lbs/cu ft	Fines (Weight) %
Specification:	≥6500	≤15	≤20	≥35	≤5
Howard Laboratory					
1 Jul 80	7869	8.4	9.3	35.0	8.7
7 Jul	9787	12.0	9.2	35.0	27.2
9 Jul	9343	10.2	8.4	37.0	4.3
14 Jul	8237	13.6	14.3	28.9	12.6
16 Jul	8390	14.5	19.2	26.7	1.8
18 Jul	9118	21.5	18.7	27.0	7.5
21 Jul	7845	17.9	23.3	23.5	4.4
22 Jul	9345	18.3	22.2	18.2	15.2
23 Jul	7922	15.9	8.9	19.8	14.0
24 Jul	8177	21.3	18.7	21.2	16.5
25 Jul	8833	23.0	31.9	21.8	10.1
30 Jul	7422	18.7	24.9	21.3	15.0
18 Aug	7571	17.1	13.2	33.5	8.1
19 Aug	6436	22.3	19.7	31.4	8.8
27 Aug	5751	20.8	22.0	39.0	22.9

TABLE 18

MINE HEAD ANALYSIS OF LUMP COAL (16:15)

	Energy Content BTU/lb	Ash Content %	Moisture Content %	Sulfur Content %
Specification:	≥14,000	≤7.5	≤5.55	≤0.7
Kenwill, Inc. Laboratory				
10 Oct 80	14,196	6.13	2.96	0.69
16 Oct	14,564	2.70	2.79	0.71
Blue Diamond Laboratory				
8 Oct	13,922	6.96	5.51	0.70
15 Oct	14,062	5.99	4.90	0.70
16 Oct	14,000	6.52	5.52	0.70
19 Oct	14,035	6.19	4.53	0.70

TABLE 19

DELIVERY ANALYSIS OF LUMP COAL (53; 54)

	Energy Content, BTU/lb	
	Heating Plant 770	Heating Plant 1240
National Bureau of Mines Laboratory		
Sep 80	14,000	13,970
Oct 80	14,148	13,970
Nov 80	13,480	13,970
Dec 80	13,735	13,915
Jan 81	13,735	13,915
Feb 81	13,573	13,915
Mar 81	13,620	13,811
Apr 81	13,601	13,811
May 81	13,601	13,811

APPENDIX D

CORRELATION BETWEEN HEATING DEGREE DAYS AND TONS OF COAL BURNED AT WRIGHT-PATTERSON AFB OH

Starting with the assumption that coal consumption depends on the severity (coldness) of the heating season, the first attempt to develop a mathematical relationship between the two utilized simple linear regression. Using historical monthly heating degree days obtained from the Air Weather Service, and the tons of coal burned for corresponding months as recorded by the 2750th Civil Engineering Squadron, it was found that a very high correlation existed between monthly heating degree days and tons of coal burned. The results from part (two years) of that analysis are shown in Table 20.

The slope and intercept for the regression equations changed somewhat from year to year. This was also implied by the lower correlation measure found when regressing the two quantities by years. The major reason for the change seems to be the modernization of the Wright-Patterson AFB heating system, which reduced the number of coal-fired plants from five to two. That change improved in the heating system's overall efficiency, causing a drop in the number of tons of coal burned per HDD as shown in Table 21 and Figure 9. The continuing improvement in building heating efficiency at WPAFB also may have played a part in the decreasing coal tons/HDD ratio.

The regression equations were not used to predict coal consumption in the final model formulation. That was

TABLE 20

SIMPLE LINEAR REGRESSION OF HEATING DEGREE DAYS WITH TONS OF COAL BURNED, WPAFB OH (4; 35)

	Month	Temperature (HDDs) x	Coal Burned (Tons) y	Linear Regression y=ax+b
	Oct	348	7296.9	
	Nov	637	7458.4	
F	Dec	888	12058.1	
Y	Jan	1063	12760.0	
8	Feb	1144	12259.6	
0	Mar	810	11044.2	a=8.89
	Apr	438	7960.0	b=3203
	May	121	4217.6	r=.980
	Jun	32	3184.2	
	Jul	0	3129.0	
	Aug	0	3208.5	
	Sep	44	2971.3	
	Oct	409	7467.7	
	Nov	577	9601.0	
	Dec	902	13028.5	
F	Jan	1391	16016.7	
Y	Feb	1242	14592.1	
7	Mar	666	11321.4	a=9.97
9	Apr	494	9104.2	b=3167
	May	185	4594.4	r=.985
	Jun	12	3259.3	
	Jul	6	2744.6	
	Aug	14	2840.0	
	Sep	65	2909.0	

TABLE 21

TONS OF COAL BURNED PER HEATING DEGREE DAY, WPAFB OH (4; 35)

Fiscal Year	Tons of Coal Burned	Heating Degree Days	Tons/HDD
1976	100,823	4673	21.58
1977	107,426	6193	17.35
1978	109,393	6633	16.50
1979	97,479	5963	16.35
1980	87,548	5525	15.85
1981 (through July)	83,752	5673	14.76

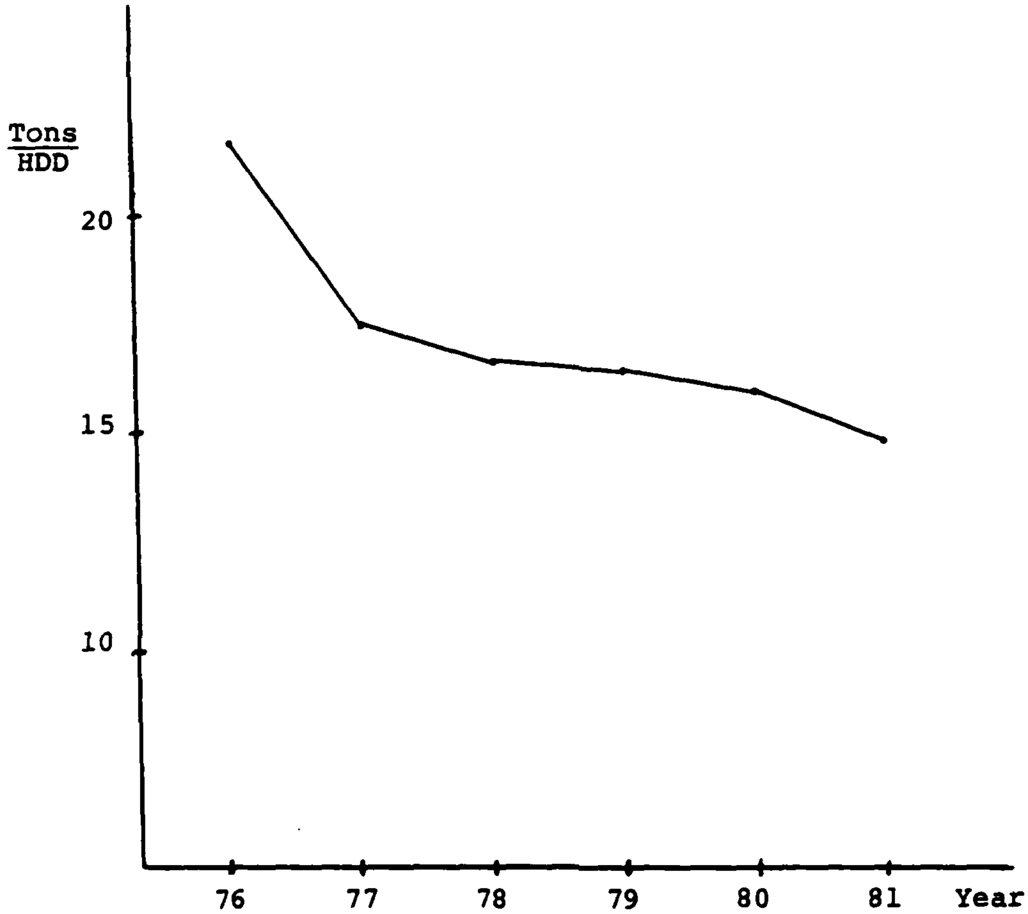

Fig. 9. Plot of Tons of Coal Burned per Heating Degree Day, WPAFB

because the coefficients changed from year to year, and because an average of the coefficients would not adequately reflect the improved efficiency for future coal consumption. Another method, described in Chapter IV, was used to predict future coal consumption. But the regression analysis does aid understanding of the base heating system, and overwhelmingly supports the notion of coal consumption being dependent on local weather temperatures.

APPENDIX E

OPERATING EXPENSE COMPONENTS FOR THE CENTRAL HEATING PLANTS AT WRIGHT-PATTERSON AFB AND THE DAYTON VETERAN'S ADMINISTRATION MEDICAL CENTER, FY 80

TABLE 22

HEATING PLANT EXPENSE COMPONENTS,
VETERANS ADMINISTRATION MEDICAL
CENTER, DAYTON OH (13)

Component	Percentage of Total Operating Cost
Fuel (Oil)	82.5
Production Labor	10.9
Maintenance Labor	0.9
Production Material	0.9
Production Overhead	2.5
Electricity & Water	1.3
Distribution Labor & Material	1.0

TABLE 23

HEATING PLANT EXPENSE COMPONENTS,
WRIGHT-PATTERSON AFB OH (18)

Component	Percentage of Total Operating Cost
Direct Material (Includes Coal)	65.6
Labor	
Civilian	15.1
Military	1.5
Facility Maintenance	13.8
Overhead	4.0

APPENDIX F

THE MODELING STEPS
(Adapted from 81:4-5)

1. Describe the problem to be solved; define the problem issues and study objectives; clearly state any assumptions made.

2. Isolate the system or process to be modeled; delineate the characteristics which can be modeled.

3. Develop or adopt a supporting theory; derive a flow or logic diagram.

4. Determine available data sources; formulate the mathematical model, analyze data requirements and design data collection procedures.

5. Collect the data; estimate parameters; choose initial conditions.

6. Flow chart the program logic of the model (describing input, processing, and output); construct and run the computer program.

7. Verify the mathematical and logical description of the problem; debug the computer program.

8. Validate the model (where possible) with reality.

9. Develop alternate conditions and analyze them using model experiments.

10. Evaluate the results and output from the model.

11. Present the results and recommendations.

APPENDIX G

WEATHER DISTRIBUTION DEVELOPMENT FOR WRIGHT-PATTERSON AFB OH

TABLE 24

HEATING DEGREE DAYS, WPAFB (4)

Year	HDDs
1951	5551
1952	5073
1953	4714
1954	5001
1955	5106
1956	5099
1957	5203
1958	5838
1959	5260
1960	5682
1961	5512
1962	5947
1963	5994
1964	5334
1965	5403
1966	6050
1967	5515
1968	5486
1969	5761
1970	5579
1971	5343
1972	5756
1973	5956
1974	5161
1975	5201
1976	5573
1977	5707
1978	6367
1979	5948
1980	5793

$\bar{x} = 5497$; $s = 380.4$

TABLE 25

HDD FREQUENCY CALCULATIONS, WPAFB

Class	Range	Observed Frequency	Relative Frequency	Cumulative Frequency
1	4601-4800	1	.0333	.0333
2	4801-5000	1	.0333	.0667
3	5001-5200	5	.1667	.2333
4	5201-5400	5	.1667	.4000
5	5401-5600	7	.2333	.6333
6	5601-5800	5	.1667	.8000
7	5801-6000	4	.1333	.9333
8	6001-6200	1	.0333	.9667
9	6201-6400	1	.0333	1.0000

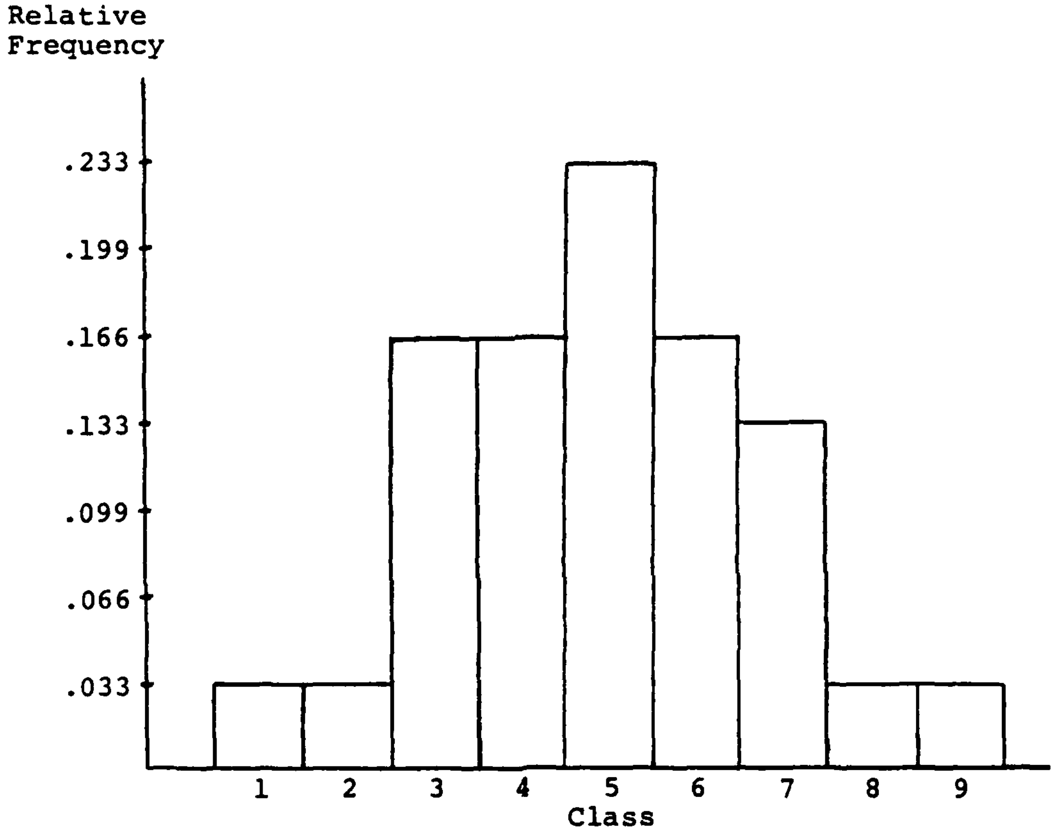

Fig. 10. HDD Frequency Distribution, WPAFB

TABLE 26

KOLMOGOROV-SMIRNOV GOODNESS OF FIT CALCULATIONS
(Yearly HDDs with Normal Distribution)

Class	Observed Frequency	Expected Frequency	Observed Cumulative Frequency	Expected Cumulative Frequency	Difference (Abs. Value)
1	1	.729	.0333	.0243	.0090
2	1	1.863	.0667	.0864	.0197
3	5	3.654	.2333	.2082	.0251
4	5	5.457	.4000	.3901	.0099
5	7	6.225	.6333	.5976	.0357
6	5	5.412	.8000	.7780	.0220
7	4	3.591	.9333	.8977	.0356
8	1	1.824	.9667	.9585	.0082
9	1	.705	1.0000	.9820	.0180

Kolmogorov-Smirnov Goodhess of Fit Test (66:78)

The largest absolute deviation for the data (Table 26) is: $D_{max} = 0.036$.

The Kolmogorov-Smirnov critical value at the 95 percent confidence level for a sample of thirty is: $D_{crit} = 0.240$.

H_0: There is no significant difference between the observed data and those which would be expected from a Normal distribution with $\mu=5497$ and $\sigma=380.4$.

H_1: There is a significant difference between the observed and expected data.

Since $D_{max} < D_{crit}$, accept H_0--the observed data does fit the hypothesized normal distribution.

Testing for Trends in the Weather Data

There was concern over the randomness of the heating degree day observations. If a trend does exist in the weather data, the validity of using a theoretical distribution to represent actual data becomes questionable.

The Cox and Stuart test showed no significant trend, but the thirty-year list of HDDs (Table 24) revealed a positive slope when a trendline analysis was performed. To settle the issue, the more powerful Spearman's ρ test for trend was accomplished.

Spearman ρ Test for Trend (21:251)

The Spearman ρ test pairs observations (annual HDDs) with the order in which taken (years) to see if the observations are time-dependent. Assuming that the yearly HDDs are not related to one another, the test hypotheses are:

H_0: The HDDs are randomly distributed.

H_1: The distribution of HDDs is time-related.

The test for trend rejects the null hypothesis if the sum of rank-difference squares is too large or too small. The test statistic is:

$$T = \sum_{i=1}^{30} [R(HDD) - R(Year)]^2$$

where R( ) is the rank of the enclosed item from lowest to highest. For the weather data in Table 24, the value for T is 2238.

The acceptance interval for a sample of thirty and a confidence level of 95 percent is found using the Hotelling-Pabst test statistic (21:389):

$$\omega_{.025} = 2868$$

$$\begin{aligned}\omega_{.975} &= 1/3\ n(n^2-1) - \omega_{.025} \\ &= 1/3\ (30)[(30)^2-1] - 2868 \\ &= 6122\end{aligned}$$

Since the value of T calculated from the data falls outside the interval $2868 < T < 6122$, H_0 is rejected at the 0.05 significance level. The conclusion from this test is that the annual HDDs are related to time.

APPENDIX H

OPERATION AND MAINTENANCE COSTS

Cost Accounting

Each fiscal year, base civil engineering receives a budget allocation. That money is converted to labor and materials used in providing services and products to base customers. The civil engineering squadron (CE Sq.) keeps track of the actual costs for resources it consumes. This "accounting" for resources used helps control costs and reduce waste (7:1).

The CE Sq. cost accounts distinguish between direct and indirect costs. Direct costs are those which can be accurately linked to a specific job, usually high-valued items. When costs cannot be accurately (or with reasonable effort) associated with a specific job they are called indirect costs. Things that would be too difficult or expensive to account for individually at each job (nails, vehicle gasoline, labor) are classed as indirect costs (7:2).

Civil engineering cost data is used to account for how much money is spent to operate and maintain various base facilities (7:7). Table 27 shows the costs recorded for operating the central heating plants at WPAFB during fiscal 1980. The first three entries are indirect costs, while the fourth is a direct cost made up largely of coal purchases.

TABLE 27

CENTRAL HEATING PLANTS OPERATING COST SUMMARY (18)[a]

	Civilian Labor	Military Labor	Overhead	Direct Material	Total
Manhours	149,890	13,689	-	-	163,579
Cost	1,197,820	116,876	318,420	5,211,880	6,844,996

[a]Cost Account 24000; Heating Plants over 3.5 MTBY; FY 80.

Operating Expenses

The cost account summary in Table 27 divides heating plant operating expenses into labor, overhead, and material. Estimating the effect on each from a change in fuel (coal to dRDF) would be difficult, however, because so many different expenses are aggregated under each heading.

A clearer view of what makes up a heating plant's operating expenses, can be gained by breaking down the heat production operation into its component activities. Table 28 contains such a list, and can be used as a starting point for analyzing how fuel changes may affect operating costs. Unfortunately, the only items in Table 28 for which cost records exist are coal, dRDF, and oil purchases; and building maintenance and repair--which enjoys its own cost account for each heating plant).

TABLE 28

OPERATION EXPENSES FOR CENTRAL HEATING PLANTS (5; 27; 34)

Plant Operation & Maintenance Activities	Fuel & Utility Purchases
Fuel Handling	Coal
Ash Handling	dRDF
Corrosion Control	Diesel Oil
Equipment Monitoring	Electricity
Equipment Inspection	Water
Equipment Maintenance	
Equipment Repair	Distribution System
Housekeeping	Maintenance & Repair
Emissions Control	
Building Maintenance & Repair	

Coal Operation & Maintenance Cost Computation

The following computations derive an operation and maintenance cost for the heating plants (FY 80) by subtracting the known expenses for coal and transportation:

$$\text{O\&M Cost} = \text{Total Cost} - \text{Fuel Cost} - \text{Transport Cost} \pm \text{Misc.}$$

FY 80 Direct Material Cost	$5,211,880
[minus] Oil Used Bldg. 1089	$ 391,049
Coal Plants' Direct Material Cost	$4,820,831
Tons of Coal Burned	87,548
[times] FOB Cost per Ton	$ 38.00
Total Coal Cost	$3,326,824
[plus] Base Supply 8% Surcharge	$ 226,146
Total Coal Cost to CE Sq.	$3,592,970
Coal Plants' Direct Material Cost	$4,820,831
[minus] Total Coal Cost to CE Sq.	$3,592,970
Other Direct Materials	$1,227,861

(Surcharge is used in finding other direct material costs, then discarded).

Tons of Coal Burned	87,548
[times] Transportation Cost per Ton	$ 11.67
Total Transportation Cost	$1,021,685

Total Labor Cost	$3,314,696
Total Coal Cost	3,326,824
Total Transportation Cost	1,021,685
Other Direct Materials	1,227,861
Overhead	318,420
Total Operating Cost	$7,209,486

Minus 5 percent in Labor, Other Direct Materials, and Overhead, adjustment for oil plant operation (two-thirds of the oil to direct material ratio).

Adjusted Total Labor Cost	$1,248,961
Total Coal Cost	3,326,824
Total Transportation Cost	1,021,685
Adjusted Other Direct Materials	1,166,468
Adjusted Overhead	302,499
*Adjusted Total Operating Cost	$7,066,437

Adjusted Total Labor Cost	$1,314,696
[plus] Adjusted Other Direct Materials	1,166,468
[plus] Adjusted Overhead	302,499
*Total O&M Cost	$2,717,928

Maintenance Labor @ 0.9%[a] of Adjusted Total Operating Cost	$ 63,598
Utilities @ 1.7%[b] of Adjusted Total Operating Cost	120,129
*Variable Portion of O&M Cost	$ 183,851

*Variable O&M Cost (per ton of coal burned):
$183,851 [divided by] 87,548 tons = 2.10 $/ton

**Fixed O&M Cost[c]
$2,717,928 [minus] $183,851 = $2,534,077

---

[a]Table 22.

[b]Table 22 plus 30 percent for coal handling instead of oil.

[c]Most of the total O&M cost is assigned to the fixed portion because labor costs show a negligible change with output (heating demand).

Operation & Maintenance Cost for dRDF

The same fixed and variable O&M costs apply to dRDF as were computed for coal. An additional charge is included for dRDF, however, because of the increased ash collection and disposal activity that will be required (Table 29).

TABLE 29

COAL AND dRDF ASH HAULING REQUIREMENTS

	dRDF	Coal	Difference
Ash Content	11%	7.5%	-
Lbs Ash/Ton	220	150	-
Lbs Collected at 98% Efficiency	215.6	147	68.6

Every ton of dRDF burned results in an extra 68.6 pounds of ash for disposal. A 1979 review of WPAFB ash disposal operations computed a per ton cost of $9.34 (68). Using a 9.67 percent O&M inflation rate for 1979-1980 (76), the 1980 per ton cost of ash collection and disposal becomes $10.24. This equates to an extra $.35 of ash disposal cost per ton of dRDF burned.

An increase in work force size has not been required to handle test burning of dRDF at WPAFB heating plants. Potential increases in boiler maintenance, operating manpower, or modifications to prevent excessive emission of toxic substances such as dioxin (15:385), may require an increase in operating funds. Those contingencies were not included in this cost model because of the uncertainty surrounding them.

APPENDIX I

ENERGY PRICE INFLATION RATES

TABLE 30

USAF FUEL INFLATION RATES (2; 3; 76)

	Annual Inflation Rate, %			
	Electricity	Coal	Natural Gas	Distillate Oil
USAF Average FY 75-80	16.0	7.1	25.2	28.4
AFESC Projected 20-25 Years	2	3	4	5
AFR 173-13 FY 81-88	- - - - - - - - - -	7.7	- - - - - - - - -	

TABLE 31

DOMESTIC INFLATION RATES[b]

Federal Pay Increases 70-79	5.9		(74:425)
Consumer Price Index 70-80	7.8		(74:488)
Producer Price Index 70-80	7.9		(74:478)
Energy Producer Price Index 71-79	19.3	14.6[a]	(74:479)
Fossil Fuels 71-79	19.0	10.5[a]	(74:607)
Industrial Fuels 78-95	4.8		(80:51)

[a]Excluding the extreme value from the sharp rise that occurred right after the 1973 oil embargo.

[b]All rates are average for the period.

APPENDIX J

RAILROAD FREIGHT CHARGE INFLATION

TABLE 32

RAILROAD FREIGHT CHARGE INFLATION (74:664)

Year	Total RR Freight Price Index[a]	% Change	Coal Freight Price Index	% Change
1970	108.8	8.8	108.6	-
1971	122.4	12.5	123.9	14.1
1972	126.1	3.0	128.8	4.0
1973	129.3	2.5	132.5	2.9
1974	149.7	15.8	154.8	16.8
1975	169.4	13.2	177.5	14.7
1976	186.6	10.2	199.6	12.5
1977	199.1	6.7	211.6	6.0
1978	213.1	7.0	228.2	7.8
1979	243.4	14.2	266.8	16.9
Ave % Change	-	9.4	-	10.6

[a]1967 = 100.

APPENDIX K

HEATING PLANT OPERATING LOG EXCERPTS, WRIGHT-PATTERSON AFB OH

TABLE 33

HEATING PLANT 770--MONTHLY MBTU
INPUT AND OUTPUT (54)

	MBTU Input	MBTU Output	Efficiency
Oct 80	86,802	72,308	.8330
Nov	140,130	115,230	.8223
Dec	181,312	145,708	.8036
Jan 81	200,040	163,239	.8161
Feb	172,729	142,648	.8258
Mar	165,298	136,038	.8230
Apr	96,096	79,198	.8242
May	83,040	68,434	.8241

TABLE 34

HEATING PLANT 1240--MONTHLY MBTU
INPUT AND OUTPUT (53)

	MBTU Input	MBTU Output	Efficiency
Oct 80	87,421	68,082	.7788
Nov	132,108	98,087	.7425
Dec	156,375	117,404	.7508
Jan 81	195,849	151,214	.7721
Feb	154,134	125,204	.8123
Mar	153,151	124,688	.8141
Apr	84,796	66,320	.7821
May	56,605	44,004	.7774

TABLE 35

WPAFB HEATING SYSTEM MBTU OUTPUT (53; 54)

	MBTU Output		
	Plant 770	Plant 1240	Total
Oct 80	72,308	68,082	140,390
Nov	115,230	98,087	213,317
Dec	145,708	117,404	263,112
Jan 81	163,239	151,214	314,453
Feb	142,648	125,204	267,852
Mar	136,038	124,688	260,726
Apr	79,198	66,320	145,518
Average Contribution to Total	.532	.468	-
Average Efficiency Jan 80 - May 81	.8124	.7965	-
Total			1,605,368

Overall Boiler Efficiency = .532(.8124) + .468(.7965) = .805

APPENDIX L

HEATING DEGREE DAY-FUEL TONNAGE RELATIONSHIP

Converting HDDs to Input MBTUs

The equation $Q=UA(\Delta t)$ is solved for UA using the heating plant MBTU output from October 1980 through April 1981, and the heating degree days for the same period. This gives a very recent value for UA, reflecting completion of heating system modifications. Including the output to input efficiency, UA becomes:

$$UA = \frac{\text{Output MBTUs}}{.805 \text{ HDDs}} = \frac{1,605,368}{(.805)(5411)} = 369$$

As a check on the accuracy of the UA factor in the heating equation, the tons of coal that should have been burned up to the end of April can be calculated. The first step is to compute the number of MBTUs needed to meet the heating demand:

$$\text{Input } Q = 369(\text{HDD}) = (369)(5411) = 1,996,659 \text{ MBTU}$$

Dividing that input Q by the heating content of coal yields tons of coal that would be burned to meet that heating demand:

$$\frac{\text{Input } Q}{\text{Coal Heat Content}} = \frac{1,996,659 \text{ MBTU}}{27.5 \text{ MBTU/Ton}} = 72,605.8$$

The actual amount of coal burned during that period was 72,034 tons, which did not include some 1400 tons of dRDF. At about half the heating value of coal, that dRDF would make up most of the difference between the predicted and actual coal tonnages.

APPENDIX M

COMPUTERIZING THE MODEL

Computerization

The heating plant model was programmed for the computer using the Q-Gert simulation language with FORTRAN subroutines. The computer flow chart for one run of this model is illustrated in Figure 11.

The Q-Gert portion of the program controls the flow of operations by starting and stopping the time. It provides the input variable (normally distributed Heating Degree Days) for each time period, and saves the computed present values for output after the run. Using Q-Gert notation, this module of the program is drawn in Figure 12.

A transaction starts through the source node at the beginning of the run and calls the user function UF. UF is a FORTRAN subroutine that computes the present value of fuel, transportation, and O&M expenses. When those actions are complete, one transaction is routed to a statistics node (simply for counting) and another is routed back to the source node through a constant, one-unit time delay. This delay simulates the incrementing of years from one to the next. At the end of twenty repetitions (base year plus nineteen future years) the Q-Gert module re-initializes certain computer variables (while saving the previous cost accumulations) according to instructions

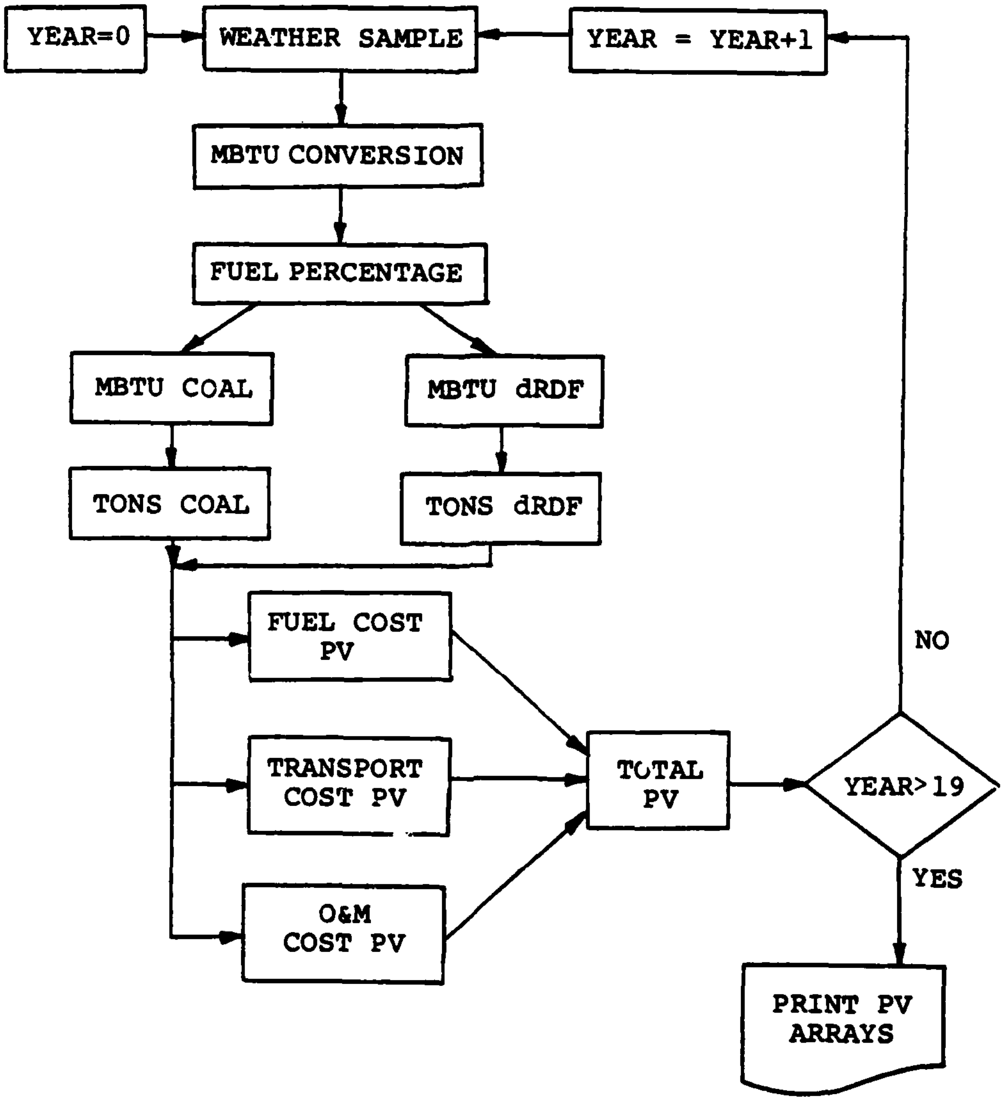

Fig. 11. Computer Flowchart

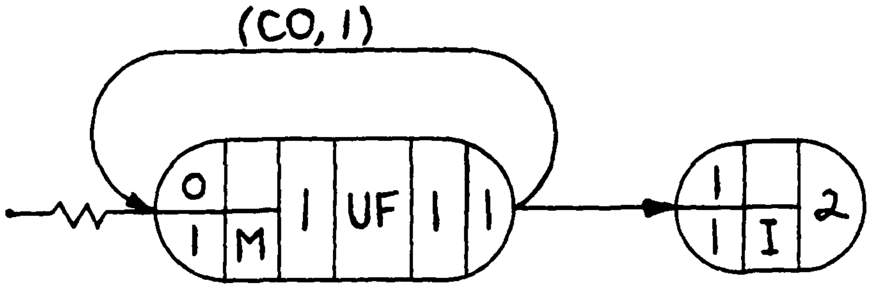

Fig. 12. Q-Gert Program Module Diagram

in subroutine UI. This cycle continues until as many runs have been completed as called for by the programmer, at which time subroutine UO is called. The UO subroutine specifies the output and format for retrieving the costs generated during several successive runs of the program. The values of key parameters used during the runs are also printed out by UO when the Q-Gert "controller" calls for this subroutine.

The succeeding pages in this appendix contain the definitions for computer variables and parameters used, the program statement listing, and a sample output from HTGPLNT.

Computer Program Variables

WSAMP--sample of annual heating degree days for WAPFB.

TNOW--simulation time; corresponds to year number.

CTON--tons of coal burned during year TNOW.

DTON--tons of dRDF burned during year TNOW

FUEL--present value of fuel cost for year TNOW.

TRAN--present value of transportation cost for year TNOW.

OM--present value of operation and maintenance cost for year TNOW.

PV--present value for year TNOW's total operating expense.

TFUEL, TTRAN, TON, TPV--cumulative values for the four previous yearly expenses.

TCOM--total of fixed and variable components of operation and maintenance expenses for coal, in year TNOW.

TDOM--total of fixed and variable components of operation and maintenance expenses for dRDF, in year TNOW.

Computer Program Parameters

PCTG--heating percentage contributed by coal.

COAL--initial coal price per tone (FOB mine).

DRDF--initial dRDF price per ton (FOB plant).

PIC--annual price inflation for coal.

PID--annual price inflation for dRDF.

RR--initial railroad ton-mile freight rate.

TIR--annual inflation in railroad transportation costs.

COM--production-variable portion of operation and maintenance expense for coal burning.

DOM--production-variable portion of O&M expense for dRDF.

OMIC--annual inflation in coal O&M expenses.

OMID--annual inflation in dRDF O&M expenses.

HCC--heating content of coal, MBTU/ton.

HCD--heating content of dRDF, MBTU/ton.

CMILE--shipping distance for coal, miles.

DMILE--shipping distance for dRDF, miles.

```
RGF,CM177000,T30.
ATTACH,QCERT,QCERTSLGO5,ID=AFIT.
FTN5.
COPYL,QCERT,LGO,RUN,,RA.
RUN.
*EOR
      FUNCTION UF(IFN)
      COMMON/QVAR/NDE,NFTBU(100),NREL(100),NRELP(100),
     :NREL2(100),NRUN,NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
      REAL WSAMP,NO,PIC,PID,TIR,OMIC,OMID,CTON,COAL,DTON,DRDF,HCC,
     :HCD,PCTG,FUEL,TFUEL,RR,TRAN,TTRAN,COM,DOM,OM,TOM,PV,TPV
      REAL TCON,TDOM
      INTEGER CMILE,DMILE
      COMMON/UCOM/PCTG,COAL,DRDF,PIC,PID,CMILE,DMILE,RR,
     :TIR,COM,DOM,OMIC,OMID,TFUEL,TTRAN,TOM,TPV
      DATA HCC,HCD/27.5,13.5/
      GO TO (1),IFN
001   WSAMP=NO(1)
      PIC=0.077
      PID=0.077
      TIR=0.094
      OMIC=0.077
      OMID=0.077
      CTON=(PCTG*369*WSAMP)/HCC
      DTON=((1.0-PCTG)*369*WSAMP)/HCD
      FUEL=CTON*COAL*((1.0+PIC)**TNOW)/((1.1+PIC)**TNOW)+
     :DTON*DRDF*((1.0+PID)**TNOW)/((1.1+PID)**TNOW)
      TFUEL=TFUEL+FUEL
      TRAN=((CTON*CMILE*RR)+(DTON*DMILE*1.17*RR))*
     :((1.0+TIR)**TNOW)/((1.1+TIR)**TNOW)
      TTRAN=TTRAN+TRAN
      TCOM=CTON*COM
      TDOM=(DTON*DOM)+(DTON*0.35)
      OM=TCOM*((1.0+OMIC)**TNOW)/((1.1+OMIC)**TNOW)+
     :TDOM*((1.0+OMID)**TNOW)/((1.1+OMID)**TNOW)+
     :2534077.0*((1.0+OMIC)**TNOW)/((1.1+OMIC)**TNOW)
      TOM=TOM+OM
      PV=FUEL+TRAN+OM
      TPV=TPV+PV
100   UF=0.0
      RETURN
      END
```

```
      SUBROUTINE UI
      COMMON/UCOM/PCTC,COAL,DRDF,PIC,PID,CMILE,DMILE,RR,
     :TIR,COM,DOM,OMIC,OMID,TFUEL,TTRAN,TOM,TPV
      INTEGER CMILE,DMILE
      DATA COAL,DRDF/38.00,27.00/
      DATA CMILE,DMILE,RR/207,381,0.056/
      DATA COM,DOM/2.10,2.10/
      PCTC=1.0
      TFUEL=0.0
      TTRAN=0.0
      TOM=0.0
      TPV=0.0
      RETURN
      END
      SUBROUTINE UO
      COMMON/QVAR/NDE,NFTBU(100),NREL(100),NRELP(100),
     :NREL2(100),NRUN,NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
      COMMON/UCOM/PCTC,COAL,DRDF,PIC,PID,CMILE,DMILE,RR,
     :TIR,COM,DOM,OMIC,OMID,TFUEL,TTRAN,TOM,TPV
      PRINT'(//T10,A)','POWER  PLANT  SIMULATION'
      PRINT'(/T30,A)',' COAL      DRDF'
      PRINT'(T5,A,2F9.2)','INITIAL FUEL COST/TON',COAL,DRDF
      PRINT'(T5,A,2F9.3)','ANNUAL FUEL INFLATION ',PIC,PID
      PRINT'(T5,A,2I9)','SHIPPING DISTANCE ',CMILE,DMILE
      PRINT'(T5,A,2F9.3)','BASE O & M EXPENSE/TON',COM,DOM
      PRINT'(T5,A,2F9.3)','ANNUAL O & M INFLATION',OMIC,OMID
      PRINT'(/T2,A,F4.2)','HEATING FRACTION FROM COAL',PCTC
      PRINT'(T2,A,F6.3)','RAIL TON-MILE FREIGHT RATE',RR
      PRINT'(/T20,A)', 'PRESENT VALUES'
      PRINT'(T2,A,E14.8,A,E14.8,A,E14.8)',
     :' FUEL ',TFUEL,' TRANS ',TTRAN,' O & M ',TOM
      PRINT'(T12,A,E14.8)','  TOTAL ',TPV
      RETURN
      END
*EOR
GEN,FEDORS,PWRPLNT,5,29,1981,1,,,19,11,S,(14)1*
SOU,1,0,1,D,M*
VAS,1,1,UF,1*
ACT,1,1,CO,1.0,1/WI-ARRIV*
ACT,1,2,,,6/TRANSFER*
STA,2/COUNT,1,1*
PAR,1,5497.,3000.,8000.,380.4*
FIN*
*EOR
```

POWER PLANT SIMULATION

	COAL	DRDF
INITIAL FUEL COST/TON	38.00	19.00
ANNUAL FUEL INFLATION	.077	.077
SHIPPING DISTANCE	207	141
BASE O & M EXPENSE/TON	2.100	2.100
ANNUAL O & M INFLATION	.077	.077

HEATING FRACTION FROM COAL .73
RAIL TON-MILE FREIGHT RATE .056

PRESENT VALUES

FUEL .26872975E+08 TRANS .95299043E+07 O & M .26801951E+08
TOTAL .63204830E+08

APPENDIX N

HTGPLNT SIMULATION RUNS

Heating Plant Simulation Run 1

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	0	0
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	0	0

Coal Percentage	1.0
Discount Rate %	0
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	0

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	55,955,522	17,069,379	53,773,819	126,798,810
s	1,037,359	316,449	57,328	1,410,998
% of Total	44.1	13.5	42.4	-

Heating Plant Simulation Run 2

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	0	0
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	0	0

Coal Percentage	.85
Discount Rate %	0
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	0

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	59,710,432	25,740,748	54,412,317	139,863,410
s	1,106,971	477,207	69,165	1,653,231
% of Total	42.7	18.4	38.9	-

Heating Plant Simulation Run 3

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	.73
Initial Fuel Cost $/ton	38.00	27.00	Discount Rate %	0
Fuel Inflation %	0	0	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	381	Freight Inflation %	0
Variable O&M Cost $/ton	2.10	2.45		
O&M Inflation %	0	0		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	62,714,360	32,677,842	54,923,116	150,314,960
s	1,162,661	605,814	78,634	1,847,532
% of Total	41.7	21.8	36.5	-

Heading Plant Simulation Run 4

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	0	0
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	0	0

Coal Percentage	.58
Discount Rate %	0
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	0

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	66,469,270	41,349,211	55,561,614	163,380,090
s	1,232,273	766,572	90,471	2,089,318
% of Total	40.7	25.3	34.0	-

Heating Plant Simulation Run 5

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	1.0
Initial Fuel Cost $/ton	38.00	27.00	Discount Rate %	7
Fuel Inflation %	7.7	7.7	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	381	Freight Inflation %	9.4
Variable O&M Cost $/ton	2.10	2.45		
O&M Inflation %	7.7	7.7		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	32,795,744	10,075,752	31,550,023	74,421,519
s	568,799	174,895	31,432	775,126
% of Total	44.1	13.5	42.4	-

Heating Plant Simulation Run 6

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.85
Discount Rate %	7
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	34,996,511	15,194,306	31,924,249	82,115,021
s	606,968	263,742	37,925	908,570
% of Total	42.6	18.5	38.9	-

Heating Plant Simulation Run 7

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.73
Discount Rate %	7
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	36,757,125	19,289,150	32,223,630	88,269,905
s	637,503	334,821	43,116	1,015,440
% of Total	41.6	21.9	36.5	-

Heating Plant Simulation Run 8

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	5.8
Discount Rate %	7
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	38,957,892	24,407,705	32,597,855	95,963,454
s	675,673	423,669	49,604	1,148,947
% of Total	40.6	25.4	34.0	-

Heating Plant Simulation Run 9

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	1.0
Initial Fuel Cost $/ton	38.00	27.00	Discount Rate %	10
Fuel Inflation %	7.7	7.7	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	381	Freight Inflation %	9.4
Variable O&M Cost $/ton	2.10	2.45		
O&M Inflation %	7.7	7.7		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	27,314,974	8,406,819	26,284,555	62,006,339
s	464,510	143,088	25,670	633,273
% of Total	44.0	13.6	42.4	-

Heating Plant Simulation Run 10

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.85
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	29,147,952	12,677,545	26,596,241	68,421,738
s	495,681	215,778	30,971	742,428
% of Total	42.6	18.5	38.9	-

Heating Plant Simulation Run 11

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.73
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	30,614,335	16,094,124	26,845,590	73,554,050
s	520,618	273,930	35,211	829,757
% of Total	41.6	21.9	36.5	-

Heating Plant Simulation Run 12

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.58
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	32,447,313	20,364,850	27,157,276	79,969,439
s	551,789	346,620	40,511	938,918
% of Total	40.6	25.5	33.9	-

Heating Plant Simulation Run 13

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	308
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.73
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4
Fixed O&M	2,280,669

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	30,614,335	16,094,124	24,368,083	71,076,542
s	520,618	273,930	35,211	829,757
% of Total	43.1	22.6	34.3	-

Heating Plant Simulation Run 14

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	.73
Initial Fuel Cost $/ton	38.00	27.00	Discount Rate %	10
Fuel Inflation %	7.7	7.7	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	381	Freight Inflation %	9.4
Variable O&M Cost $/ton	1.89	2.24		
O&M Inflation %	7.7	7.7		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	30,614,335	16,094,124	26,832,118	73,540,578
s	520,618	273,930	31,925	826,471
% of Total	41.6	2[illegible]9	26.5	-

Heating Plant Simulation Run 15

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	.73
Initial Fuel Cost $/ton	38.00	27.00	Discount Rate %	10
Fuel Inflation %	7.7	7.7	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	381	Freight Inflation %	8.5
Variable O&M Cost $/ton	2.10	2.45		
O&M Inflation %	7.7	7.7		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	30,614,335	16,019,080	26,845,590	73,479,005
s	520,618	272,527	35,211	828,356
% of Total	41.7	21.8	36.5	-

Heating Plant Simulation Run 16

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	.73
Initial Fuel Cost $/ton	38.00	27.00	Discount Rate %	10
Fuel Inflation %	8.5	7.7	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	381	Freight Inflation %	9.4
Variable O&M Cost $/ton	2.10	2.45		
O&M Inflation %	7.7	7.7		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	30,698,366	16,094,124	26,845,590	73,638,081
s	522,187	273,930	35,211	831,326
% of Total	41.7	21.9	36.4	-

Heating Plant Simulation Run 17

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	.73
Initial Fuel Cost $/ton	38.00	27.00	Discount Rate %	10
Fuel Inflation %	7.7	7.7	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	381	Freight Inflation %	9.4
Variable O&M Cost $/ton	2.10	2.45		
O&M Inflation %	7.7	8.5		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	30,614,335	16,094,124	26,849,672	73,558,131
s	520,618	273,930	35,287	829,833
% of Total	41.6	21.9	36.5	-

Heating Plant Simulation Run 18

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost \$/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	141
Variable O&M Cost \$/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.73
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	30,614,335	9,821,906	26,845,590	67,281,840
s	520,618	167,174	35,211	722,989
% of Total	45.5	14.6	39.9	-

Heating Plant Simulation Run 19

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	22
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.73
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	30,614,335	6,711,932	26,845,590	64,171,857
s	520,618	114,240	35,211	670,069
% of Total	47.7	10.4	41.8	-

Heating Plant Simulation Run 20

	Coal	dRDF
Energy Content MBTU/ton	27.5	14.85
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.72
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	29,730,193	15,440,119	26,775,053	71,945,364
s	505,583	262,798	34,012	802,390
% of Total	41.3	21.5	37.2	-

Heating Plant Simulation Run 21

	Coal	dRDF
Energy Content MBTU/ton	27.5	16.2
Initial Fuel Cost $/ton	38.00	27.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.70
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	29,004,189	15,104,354	26,728,556	70,837,099
s	493,237	257,083	33,221	783,539
% of Total	40.9	21.3	37.7	-

Heating Plant Simulation Run 22

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	19.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	7.7

Coal Percentage	.73
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	27,451,548	16,094,124	26,845,590	70,391,263
s	466,833	273,930	35,211	775,972
% of Total	29.0	22.9	38.1	-

Heating Plant Simulation Run 23

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	19.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	381
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	8.5

Coal Percentage	.73
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	27,451,548	16,094,124	26,849,672	70,395,345
s	466,833	273,930	35,287	776,048
% of Total	39.0	22.9	38.1	-

Heating Plant Simulation Run 24

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	19.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	141
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	8.5

Coal Percentage	.73
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	27,451,548	9,821,906	26,849,672	64,123,072
s	466,833	167,174	35,287	669,317
% of Total	42.8	15.3	41.9	-

Heating Plant Simulation Run 25

	Coal	dRDF
Energy Content MBTU/ton	27.5	13.5
Initial Fuel Cost $/ton	38.00	19.00
Fuel Inflation %	7.7	7.7
Shipping Distance mi.	207	22
Variable O&M Cost $/ton	2.10	2.45
O&M Inflation %	7.7	8.5

Coal Percentage	.73
Discount Rate %	10
Freight Rate ¢/ton-mi.	5.6
Freight Inflation %	9.4

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	27,451,548	6,711,932	26,849,672	61,013,152
s	466,833	114,240	35,287	616,359
% of Total	45.0	11.0	44.0	-

Heating Plant Simulation Run 26

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	.73
Initial Fuel Cost $/ton	38.00	19.00	Discount Rate %	10
Fuel Inflation %	4.8	4.8	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	141	Freight Inflation %	4.8
Variable O&M Cost $/ton	2.10	2.45		
O&M Inflation %	4.8	4.8		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	27,025,032	9,583,828	26,338,112	63,037,881
s	458,888	162,734	309,761	656,235
% of Total	42.9	15.2	41.8	-

Heating Plant Simulation Run 27

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	.73
Initial Fuel Cost $/ton	38.00	19.00	Discount Rate %	10
Fuel Inflation %	7.7	7.7	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	141	Freight Inflation %	7.7
Variable O&M Cost $/ton	2.10	2.45		
O&M Inflation %	7.7	7.7		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	27,451,548	9,735,083	26,845,590	64,032,312
s	466,833	165,552	35,211	667,571
% of Total	42.9	15.2	41.9	-

Heating Plant Simulation Run 28

	Coal	dRDF		
Energy Content MBTU/ton	27.5	13.5	Coal Percentage	.73
Initial Fuel Cost $/ton	38.00	19.00	Discount Rate %	10
Fuel Inflation %	10.5	10.5	Freight Rate ¢/ton-mi.	5.6
Shipping Distance mi.	207	141	Freight Inflation %	10.5
Variable O&M Cost $/ton	2.10	2.45		
O&M Inflation %	10.5	10.5		

	Fuel	Transportation	Operations & Maintenance	Total
$\bar{x}$	27,852,797	9,877,376	27,237,462	64,967,544
s	474,332	168,211	35,777	678,358
% of Total	42.9	15.2	41.9	-

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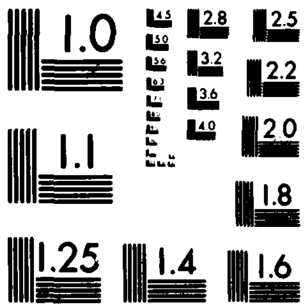

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